SolarPaq

USER MANUAL

for use with

insight software

Issue 1

MA5050A

DATAPAQ®
A Fluke Company

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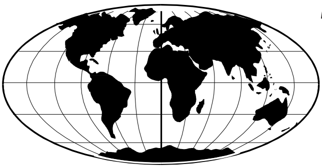

Datapaq® is the world's leading manufacturer of process temperature-monitoring instrumentation. The company maintains this leadership by continual development of its advanced, easy-to-use systems.

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DATAPAQ PART NO. MA5050A

SAFETY WARNINGS

For safe use of Datapaq equipment, always:

- Take care to follow its supplied instructions.
- Observe any warning signs shown on the equipment itself.

Indicates **potential hazard**.

On Datapaq equipment this normally warns of high temperature, but where you see the symbol you should consult the manual for further explanation.

Warns of **high temperatures**.

Where this symbol appears on Datapaq equipment, the surface of the equipment may be excessively hot (or excessively cold) and may thus cause skin burns.

Manual set in 10 pt Gill Sans.

User manuals are available in other languages; contact Datapaq for details.

CONTENTS

Introduction

Datapaq® SolarPaq, incorporating Insight™ Solar Tracker® software, is a complete system for monitoring and analyzing the temperature profiles of products within a wide range of heat-treatment processes used in the manufacture of photovoltaic cells. Power and flexibility make SolarPaq a perfect tool for process-temperature monitoring, from commissioning and troubleshooting to process optimization, ensuring consistent quality of product and maximum efficiency.

Insight software's innovative **analysis techniques** help in identifying problems, fine-tuning the process and reducing running costs. Powerful **reporting** facilities allow the user to generate customized printouts, including any or all of the analysis results or raw temperature data.

The materials and procedures detailed in this manual are intended to aid SolarPaq users in obtaining accurate and repeatable temperature profiles. Datapaq has developed specific solutions for the most commonly profiled processes used in the manufacture of crystalline photovoltaic cells, and these are covered here in some detail. There is also general guidance on the considerations to be followed when using the SolarPaq system in associated industries such as the manufacture of thin-film photovoltaic cells.

This manual contains the following sections:

- **Basic Hardware and Its Use** (p. 9) – An introduction to thermal barriers and thermocouple probes, their specifications, and use.
- **Running a Temperature Profile** (p. 17) – The stages of obtaining a temperature profile that are common to all processes in the manufacture of photovoltaic cells, including the use of **hardwired telemetry** to follow the development of the temperature profile in real time.
- Aspects of using the SolarPaq system that are specific to different processes: **anti-reflective-coating (sputtering)** (p. 23), **contact-firing (metallization)** (p. 27) and **module lamination** (p. 31).

The dedicated manual supplied with the **data logger** should be read in conjunction with this manual. It provides information on operating the logger, including:

- Installing Insight and establishing communication between logger and PC.
- Resetting the logger with new data-collection parameters.
- Downloading the collected data to the PC.
- Use of telemetry.
- Troubleshooting logger problems.

For full details on use of the Insight software, refer to the online Help system available after the software is installed.

Basic Hardware and Its Use

To accommodate the range of different processes which are involved in the manufacture of photovoltaic cells, SolarPaq systems are supplied in a variety of configurations, depending on the intended application. The information in this chapter applies to all systems. Some processes in cell manufacture require special additional considerations, and these are dealt with separately:

- Anti-reflective coating (sputtering) processes (p. 23).
- Contact firing (metallization) (p. 27).
- Module lamination (p. 31).

*For use of the **data logger**, and for any further special-purpose hardware, see the documentation supplied with it.*

System Components

A typical SolarPaq system comprises:

- Data logger, with communications lead and charger.
- Data logger user manual (specific to the logger model).
- Thermal barrier – to protect the logger during its time in the furnace.
- Thermocouple probes.
- *SolarPaq User Manual.*
- Insight Solar Tracker software.

Thermal Barriers

The thermal barrier provides the thermal and mechanical protection necessary for the data logger to survive in the hostile environment of the furnace.

A range of barriers is available to suit different loggers and different processes, and the specification and use of a selection of these are described in the appropriate sections of this manual.

Micro-porous ceramic insulation covered by a ceramic fiber cloth provides the primary thermal protection, enabling the system to operate at high temperatures for extended periods.

*When used in **vacuum processes**, and when the barrier has been left standing for some time, the vacuum may take longer than normal to pump out due to out-gassing from the ceramic insulation.*

Selecting a Thermal Barrier

Before running a temperature profile of a given process, the user must ensure that the SolarPaq system is suitable.

The thermal barrier used must have a specified thermal duration which exceeds that of the time/temperature profile to be experienced within the process (see barrier specifications elsewhere in this manual).
Failure to ensure use of a suitable thermal barrier may lead to the barrier and/or logger suffering irreparable damage.

The **physical size** of the SolarPaq system (primarily the thermal barrier) needs to be considered in order to ensure that it can freely and safely pass through the process. Particular attention must be given to ensuring that it can be safely loaded into and recovered from the furnace.

In case of any doubts on the choice of thermal barrier, contact Datapaq with full details of the process.

Thermocouple Probes

Thermocouple probes utilize the Seebeck effect, discovered in the nineteenth century, by which an e.m.f. is produced in any electrically conducting material that is not at uniform temperature. The actual voltage measured is proportional to the temperature difference between the thermocouple's 'hot' and 'cold' junctions (the hot junction being the measurement junction, and the cold junction being the junction of thermocouple and measurement instrumentation).

The practical implementation of thermocouples requires sophisticated electronics to eliminate potential measurement errors which include poor linearity over the measurement range, and inaccuracy due to temperature variations at the cold junction. To accommodate these the electronics in the measuring system must simulate a temperature of 0°C at the cold junction, as well as compensating for any non-linearity over the range of thermocouple operation.

Over the years, 'standard' thermocouples have been developed using materials chosen for sensitivity, linearity (consistency of sensitivity over the useful temperature range), price and availability. Current standards include types K, N, R, S and T, each type being identified by its connector color.

Thermocouple Specifications

The standard thermocouple probe for furnace operation in photovoltaic-cell manufacture is **type K**, which has a hot junction combining nickel-chromium alloy and nickel-aluminum alloy. International specifications for type K define a sensitivity and linearity over the range 0–1,250°C, though operating range is limited in practice by the cable insulation (see below).

Probe Type	Temperature Range	Cable Insulation	Accuracy of Probes Supplied by Datapaq
K	-150°C to 1,370°C	Mineral, PTFE, ceramic	±1.1°C (or ±0.4% if greater) at 0–1,250°C

Type K thermocouples supplied by Datapaq are supplied with **green connectors and cables**, following the IEC584 color standard.

Thermocouple Cable Insulation

The practical operating temperature of the thermocouple probes is limited by the cable insulation material's temperature characteristics. In processes used for the manufacture of photovoltaic cells, the probe insulation recommended is primarily mineral and PTFE.

Insulation	Upper Temperature Limit
Mineral insulation (MI)	1,250°C
PTFE	265°C
Binder-less glass fiber	1,000°C

Mineral-insulated (MI) probes have an enclosed junction providing increased immunity to electrical interference, which is particularly useful in sputtering processes (p. 23). They are less flexible than PTFE, but suitable for use up to 1,250°C.

Binder-less glass fiber provides a very lightweight flexible insulation suitable for high temperatures. It is used in processes such as contact firing.

PTFE (polytetrafluoroethylene)-insulated probes are suitable for general-purpose use at temperatures up to 265°C. PTFE is a robust, flexible, non-stick material, with a low thermal mass and therefore a quick response time.

WARNING

PTFE does not support combustion, but decomposes above 265°C producing small amounts of toxic fumes.

The important products from PTFE thermal decomposition are as follows.

At Temperatures Greater Than	Product
400°C	See note*
430°C	Tetrafluoroethylene
440°C	Hexafluoropropylene
475°C	Perfluoroisobutylene
500°C	Carbonyl fluoride*, which, in moist air, converts to the acid gas hydrogen fluoride

* May also be produced if PTFE tape is kept at 400°C for an extended time.

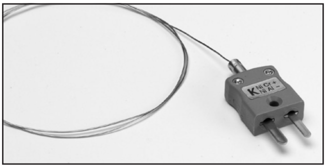
Health-hazard Data

- Inhalation of decomposition products from PTFE can produce 'polymer fume fever', which has symptoms similar to influenza.
- There is no risk from ingestion or skin contact.
- There are no medical conditions generally aggravated by exposure to PTFE.

Emergency and First-aid Procedures

- If there is accidental contact with PTFE fumes, remove the person concerned to clean air.
- Self-contained breathing apparatus and protective clothing should be worn when fire-fighting.

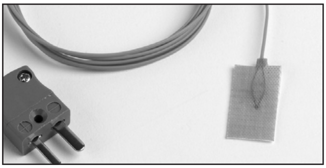
Thermocouple Types and Accessories



Ultra-fine High-temperature Thermocouples

Mineral-insulated cable, diameter 0.5 mm. Complies with BSEN 60584.2 Class 1. Maximum 1,100°C for short durations.

PA1570 0.3 m/1 ft
PA1571 0.6 m/2 ft
PA1572 1.0 m/3.3 ft



Adhesive-patch Thermocouple

Attaches directly to light-gauge metal or plastic with adhesive patch and/or high-temperature tape. Ideal where fast response is required or in infra-red processes. PTFE-insulated cable. Maximum 265°C.

PA0061 1.0 m/3.3 ft
PA0060 1.5 m/4.9 ft
PA0062 3.0 m/9.8 ft

Binder-less Glass-fiber Thermocouple

1/0.2 flat-pair cable, hot junction flattened for improved thermal contact. Complies with ANSI MC96.1 Special Limits of Error. Maximum 1,000°C.

PA1144 0.5 m/1.6 ft
PA1145 1.0 m/3.3 ft

Kapton Tape – High-temperature Adhesive

For securing exposed-junction thermocouples. Pressure-sensitive silicone adhesive. Maximum 400°C.

HT0090 9 m/29.5 ft

Working with Thermocouple Probes

Datapaq probes cover a huge range of possible usages. Choose suitable types for your process, and for the individual probes' locations, from those listed above.

The **process temperature** may determine the choice of thermocouples' insulation material. PTFE is to be preferred if the temperature of the process is low enough to permit its use; see p. 11.

The mechanical design of the **thermocouple tip** (the hot junction) needs to be suitable for the product to which it will be attached. For measuring surface temperature of a crystalline cell, a very lightweight flat tip is best. When measuring the temperature of thicker glass panels, a heavier probe can be used for greater robustness.

The **length** of the thermocouples should be selected to ensure that there is adequate wire to connect the product back to the data logger, but they should not be so long that excess wire could get caught or trapped as the system passes through the process.

The **thermocouple type** (K, N, R, S or T) must match that of the data logger used.

Probe Location

The product's geometry and the process's thermal requirements define the number and location of the thermocouples required for the test. In some instances it is necessary to install an array of thermocouples to provide coverage over the entire area of the product. In others, the thermocouples are located to monitor a specific part of the product.

Probe Attachment

Attaching probes to the product is a key step in obtaining accurate and repeatable temperature profiles. There are a number of options, depending on the exact nature of the product and the temperatures at which it is processed:

- **Adhesive tape**.
- **Adhesive cement**, either high-temperature epoxy or ceramic can be used.
- **Mechanical attachment** using a clamping mechanism.

*The **thermal mass** of the thermocouple tip and of its fixing method must be low compared to that of the product. This will ensure that measurements are a true reflection of the product temperature that would occur in normal production.*

*The tip of the thermocouple probe must be in **good mechanical contact** with the product when monitoring surface temperature. Poor thermal contact will at best result in slowing the rate at which the product heats the probe and at worst prevent the probe from achieving the same temperature. Ensure probe tips are clean before attaching.*

*To assist repeatability and obtain maximum lifetime from the probes, it is preferable to use as a **test-piece** a standard example of the product to which the thermocouples are permanently attached.*

Testing Thermocouple Probes

Although thermocouples are generally robust, they can be damaged during handling. To confirm their correct operation after installation, either:

- Set up the system as if to monitor a profile run using hardwired telemetry (see p. 21 for details), and note the temperatures registered by the thermocouples as they are displayed in Insight – *or*
- Use a type-K digital thermometer, attaching each thermocouple in turn to the thermometer's connector – *or*
- With a full set of thermocouples attached to the logger, and the logger connected to the PC, open the Diagnostic section of the Communications Setup dialog in Insight; this shows current probe temperatures.

Proceed as follows.

1. Note readings first at ambient temperature: thermocouples registering no data in Insight, or an open circuit with a digital thermometer (*OC* in the Communications Setup dialog), may be broken. Inconsistent readings may indicate an intermittent short circuit.
2. If a satisfactory ambient reading is recorded, apply heat to the thermocouple-tip via fingers or other heat source. An increased temperature should register:

- If the reading does not change, the thermocouple is short circuit and must be replaced.
- If the probe measures air temperature, the cable may have damage which has created a new hot junction.
- If the thermometer shows a decrease, the thermocouple connections are reversed.

3. Confirm correct operation at 100°C by placing the thermocouple-tip in boiling water.
4. Replace any thermocouples with damaged cables.

Running a Temperature Profile

The information in this chapter applies to all SolarPaq systems, and should be read in conjunction with detailed guidance on use of the specific system:

- Anti-reflective coating (sputtering) processes (p. 23).
- Contact firing (metallization) (p. 27).
- Module lamination (p. 31).

A temperature profile can be acquired by two means:

- **Standard profiling** – After the logger and product have been passed through the furnace, data is downloaded from the logger into the PC to be displayed and analyzed by the Datapaq Insight software.
- **Using hardwired telemetry** – As the logger gathers data from the product inside the furnace, this is communicated directly to the PC by a hardwired connection. The temperature profile can be watched developing as it happens, i.e. in real time. See p. 21.

This chapter describes the basic stages of running a product or test-piece through the furnace in order to obtain a temperature profile without telemetry.

Overview

Before running your product and the data logger through the furnace you will use the Insight software to reset the logger, i.e. to prepare it for receiving fresh data. After the logger has been retrieved from the furnace, you will use Insight again to download the profile data and save it to disk. The stages are as follows.

- Choose positions for, and attach, the thermocouple probes.
- Setup communication between the data logger and your PC (if this has not already been done for a previous profile run).
- Reset the data logger so that it is ready to receive fresh data; in the process of doing this you will also be able to set the sample collection interval and the method used to trigger the start of data collection, and to check the logger's battery status.
- Install the logger in its thermal barrier.
- Run the test-piece and logger/barrier through the furnace.
- Download the data from the logger into the Insight software.

- If necessary, set the furnace start position within the data.
- Add any additional information that you wish to have recorded with the profile data.

After this, Insight can be used to analyze the profile data as required.

Preparing the Logger

If the data logger is being connected to a PC for the first time, it is necessary to enable communication between them. The logger must also be reset before a profile run – using Insight software – to establish its data-collection parameters. See the dedicated user manual for your logger, or Insight's Help system.

*Note that the logger's recommended **sample interval** (selected during the reset process) differs according to the process being monitored. See the relevant section of this manual.*

If there is any doubt that the logger's battery charge may be inadequate for the profile run, this must also be checked by using the reset procedure.

For the procedures involved, see your dedicated logger manual or the Insight Help system. Note that, since its last use, the logger must have cooled below 35°C (comfortable to hold without gloves).

Installing the Logger in the Thermal Barrier

Ensure the thermal barrier has cooled sufficiently since its last use.

1. Plug the thermocouples into the logger's numbered sockets. If you are using a process file, ensure that the probe/socket numbers on the logger correspond to those used to define probe numbers and locations in that file (see the Insight software for an introduction to process files: press function key F1, or select Help > Contents from the menu bar, and click the section 'Process Files: Furnace, Recipe, Product').
2. Ensure the barrier's seals are clean and undamaged. A good seal between thermal barrier and thermocouple cables is essential if the data logger is to be protected. Ensure that the thermocouple cables do not cross over where they exit the barrier, as this will ensure the best possible seal when the barrier is closed.

3. If the trigger mode is Start Button, press and hold the start button for about 1 second until the green LED starts to flash.
4. Close the thermal barrier, ensuring that the lid is securely fastened.

Placing the System in the Furnace

Line speed through the furnace may be very high, so care must be taken to prepare everything before loading any part of the system into the process. It is often the case that access space, and access time, at the entrance to the process are limited, so plan how you intend to install the system.

1. Place the instrumented test-piece onto the furnace's conveyor or loading mechanism with the thermocouple cables towards the rear, ensuring that the assembly is positioned such that it will not foul any part of the furnace as it passes through. In most applications, the best results are obtained if the test-piece enters the process before the thermal barrier, ensuring least thermal disturbance as the product temperature measurements are taken.
2. If the system will be in the process for a long time, note the time at which it entered so that the expected exit time can be calculated.

Removing from the Furnace and Downloading Data

WARNING

The thermal barrier – and possibly the logger – will be ***hot****. Use protective gloves.*

Recover the system as soon as it exits the furnace – or at the first opportunity that access to the system is feasible and safe. Sufficient space must be available near the furnace to allow appropriate handling procedures.

Open the thermal barrier and **remove the logger**.

Failure to remove the logger from the hot thermal barrier could damage the logger.

Opening the thermal barrier fully and placing it on a cold surface will increase its rate of cooling.

If the setup permits, the thermocouple probes can be left in place for subsequent profile runs. Leaving the thermocouples in place will reduce wear and cable stress and so maximize their life.

If it is necessary to **stop data acquisition manually**, press and hold the logger's red stop button until the red and green logger-status LEDs are on simultaneously. A red logger-status LED flashing every 5 seconds indicates data stored in the logger but not yet downloaded to the PC.

Download the data from the logger to the PC using the Insight software. For the procedures involved, see your dedicated logger manual or the Insight Help system (on Insight's menu bar, select Help > Contents).

Preparing the Data for Analysis

For full details of Insight's powerful analysis capabilities, see the online Help system: on Insight's menu bar, select Help > Contents > Data Analysis. Before starting full analysis of the downloaded data, it may be advisable to:

- Apply a **process file** (see the Insight software for an introduction to process files: press function key F1, or select Help > Contents from the menu bar, and click the section 'Process Files: Furnace, Recipe, Product').
- Specify the **furnace start position** in the data (see below).
- Apply **thermocouple correction factors** to the data (see below).
- Record any **notes** specific to the profile run (see below).

Specifying Furnace Start

If you have not applied a process file to the data during download (see above), or if the process file you applied did not specify that the **furnace start position** be adjusted, you may want to adjust the furnace start position now: from the menu bar, select Process > Adjust Furnace Start, or use the right-click menu.

This can be valuable as it permits different paqfiles, i.e. data from different temperature profile runs, to be compared with each other. If you do not wish to adjust the furnace start at this point, you may still do so at any time subsequently.

For an explanation of furnace start, and how to adjust it, click Help in the Adjust Furnace Start dialog.

Thermocouple Correction Factors

It is possible to increase accuracy by using calibration data for the thermocouples to establish correction factors. If correction factors are known for a range of temperature values, and if a linear relationship is assumed between adjacent temperature values, appropriate corrections can then be applied to all data within the calibrated temperature range. Insight stores these correction factors in a 'correction factor file', and correction is achieved simply by applying this file to the data.

For details of the creation and use of correction factor files, see the topic 'Correction Factors' in Insight's online Help system.

Storing Notes and Printing a Report

To use Insight to store any **notes or photos** which you may wish to associate with the profile-run data, select Edit > Notes.

To select options for **printing a customized report** of the profile-run data and its analysis results, select File > Print Options.

Using Hardwired Telemetry

In addition to the standard off-line analysis, real-time analysis by hardwired telemetry is possible with Insight software.

Thus, with thermocouples trailing from the furnace and attached to the logger outside the furnace, data being gathered by the logger is transmitted via the communications lead directly to the PC, and the temperature profile can be watched developing as data is received, i.e. in real time.

After the run is completed, the received data can be saved as a new paqfile (data is also stored internally in the logger during the run, so it is also possible to download the data from logger to PC after the run is finished and to save that as the final paqfile).

This procedure is most easily carried out by using Insight's **Trailing Lead Wizard** to guide you, step-by-step, through this method of running a profile: click on the Insight toolbar, or select Tools > Wizards from the menu. For further guidance, see Insight's Help and your dedicated logger manual.

Troubleshooting

Checking Thermocouple Probes

Thermocouple probes are generally reliable, but damage resulting from inappropriate use or handling can produce erroneous readings. If you suspect that invalid data may have been introduced into your temperature profile (paqfile), select the View Data tab in the Insight software's Analysis Window to view the raw data as downloaded from the logger. The various types of invalid data which may be contained in a paqfile are shown in the analysis grid as follows.

OC	Open circuit.
NA	Data not available.
LO	Temperature measured was below the range of the logger.
HI	Temperature measured was above the range of the logger.
***	Calculation cannot be performed (not necessarily because the data are invalid). Does not appear in View Data analysis mode.

Probes with an intermittent open circuit may produce spiky, erratic profiles. Note that spikes are inevitable if probes are disconnected from the logger while it is still gathering data. Typical causes of invalid or interrupted data are:

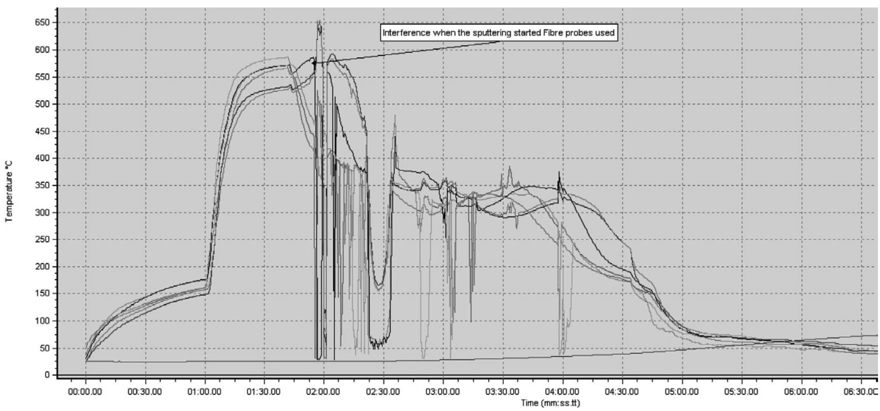
- Thermocouple becoming detached from the logger.
- Faulty connection.

Faulty thermocouple readings which are inconsistent with those of other probes may be caused by a short circuit where un-insulated wires touch before the hot junction. This is known as a 'false hot junction' and can even occur within the thermal barrier if the insulation is damaged there.

In all cases the probe concerned must be replaced.

Interference

Erratic or spiky readings can be caused by excessive external electrical interference, though this can normally be eliminated by use of the appropriate thermocouple type. This is a particular problem when monitoring the sputtering process used to place the anti-reflective coating onto photovoltaic cells (p. 23) where the SolarPaq system is exposed to the plasma – and in this case isolated-junction mineral-insulated probes are recommended. Use of ceramic- or glass-fiber-insulated probes within the energized plasma may lead to erratic and erroneous readings.



*Temperature profile from a sputtering process, showing typical interference caused if the profile is **not** conducted using isolated-junction mineral-insulated thermocouples.*

Anti-reflective Coating (Sputtering)

The following SolarPaq hardware, and procedures, are employed to monitor sputtering and other processes used in applying an anti-reflective silicon nitride coating during photovoltaic cell manufacture.

Close monitoring of the coating process is key to optimizing it and hence to the final efficiency of the photovoltaic cell. The SolarPaq system can pass through the entire process measuring the temperatures on the cell surfaces, thereby providing data on what is happening at all points inside the process.

The logger and its thermal protection can simply be placed into the photovoltaic-cell carrier frame while it passes through the process. The design enables the SolarPaq system to occupy one of the 156-mm cell positions, so no modification of the carrier is needed. The system then passes through the entire process with plasma fields energized as during normal production.

Guidance given in this chapter on using the SolarPaq system with anti-reflective-coating (sputtering) processes is additional to general descriptions of materials and procedures given elsewhere (p. 9 *and p.* 17) *and should be read in conjunction with that.*

Thermal Barrier

For general guidance on the use and selection of thermal barriers, see p. 9.

The barrier for anti-reflective-coating processes is designed for use with the Q18 data logger, standard 6-channel model, type K (DQ1863).

TB7400

Temp °C	450				
Duration (mins)	8				
Dimensions	Height 18 mm 0.7 in.	Width 149 mm* 5.9 in.	Length 148 mm* 5.8 in.	Weight 0.44 kg 1.0 lb	

* Securing flanges 10 mm wide are fitted to three sides.

By using the spacer blocks provided with the thermal barrier, the height above and below the carrier frame can be set to suit the dimensions of the process chamber.

Q18 data logger in place in TB7400 thermal barrier, for use in anti-reflective-coating processes.

Thermocouples

For anti-reflective-coating processes the recommended thermocouples are isolated-junction mineral-insulated types. These provide maximum protection against the electrical fields created within the processes plasma chamber. Use of any other type of thermocouple may result in erratic and/or erroneous readings (see p. 22).

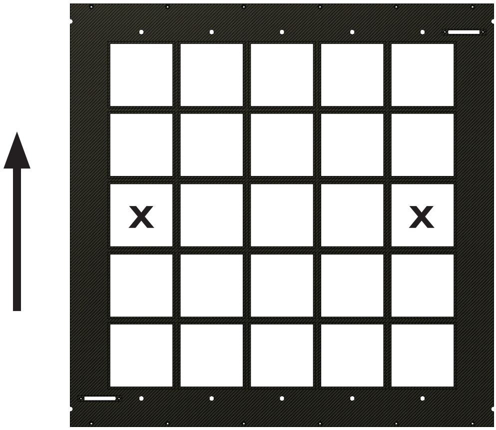
Datapaq ultra-fine high-temperature thermocouples are recommended (PA1570, p. 12).

Probe Location and Attachment

The method of attaching the probe to the photovoltaic cell will depend on process temperature. At lower temperatures, Kapton tape (p. 12) can be used as a quick way of obtaining reasonable results; the tape will probably have to be replaced after each profile run. At higher temperatures the probes can be held in place either by high-temperature adhesive or simply by bending the thermocouple cable into an arc so that the cable's springiness maintains contact with the cell.

The number and position of photovoltaic cells to be monitored will be decided by the process engineer, and depends on the furnace and on the reason for profiling it.

The thermal barrier should be located in the carrier frame as close as possible to one side and midway between front and rear of the carrier. This will reduce the chance of the system's weight causing the carrier to sag when it is being heated in the chamber. The thermocouple cables should be routed together back to the logger and thermal barrier in such a way as to minimize the chance of them catching in the process chamber.



Typical carrier frame for photovoltaic cells in an anti-reflective coating (sputtering) process. SolarPaq thermal barrier assembly should be placed at either position marked by X. Arrow shows the direction of travel through the process.

It is preferable to use a dedicated carrier with thermocouple probes left in place for subsequent profile runs. Leaving the thermocouples in place will reduce wear and cable stress and so maximize their life.

Running a Temperature Profile

See p. 17 for general procedure.

Preparing the Logger

Set the **sample interval** to 0.5 s. This will give adequate resolution of the data, while a shorter sample interval may result in electrical interference being seen in the results (see p. 22). At a sample interval of 0.5 s or greater, the internal circuits of the logger are configured for maximum interference rejection.

Installing the Logger in the Thermal Barrier

The thermal barrier should be installed into the carrier frame as described above and the thermocouples placed one each in the exit slots in the front face of the barrier.

Placing the System in the Process Chamber

With the SolarPaq system installed in the carrier frame, load the carrier into the process chamber using its automatic loading system.

Checking the Temperature Profile

In using Insight to analyze the profile data after downloading from the logger, ensure that you have selected 'anti-reflective' as the furnace type. This is best done by use of a **process file** (for detailed guidance on use of process files, press function key F1, or select Help > Contents from the menu bar, and click the section 'Process Files: Furnace, Recipe, Product'). Alternatively, set the furnace type on the Furnace tab of the Process Details dialog: click on the Insight toolbar, or select Process > Process Details from the menu.

Select the dedicated **Anti-reflective analysis mode** from the tabs at the bottom of the Insight window. Of particular interest will be analysis data on peak temperature, rising/falling slopes, and mean slope between two user-specified temperatures.

Contact Firing (Metallization)

Obtaining optimum performance from a photovoltaic cell depends critically on the contact-firing process. Incorrect temperature profiles will affect contact resistance as well as fill factor and hence directly reduce production yields. Using the SolarPaq system the logger travels through the furnace recording temperature profiles from up to six points on the top and bottom of a test cell, and the process is thus monitored without disrupting normal production.

SolarPaq hardware and procedures appropriate to use in contact-firing processes are as follows.

Guidance given in this chapter on using the SolarPaq system with contact-firing processes is additional to general descriptions of materials and procedures given elsewhere (p. 9 *and p.* 17) *and should be read in conjunction with that.*

Thermal Barriers

For general guidance on the use and selection of thermal barriers, see p. 9.

The two barriers suitable for contact-firing processes differ in their thermal duration. Both are designed for use with the Q18 data logger, standard 6-channel model, type K (DQ1860).

TB7200

Temp °C	200	400	600	800	
Duration (mins)	6.5	2.0	1.5	1.0	
Dimensions	Height 19.5 mm 0.8 in.	Width 165 mm 6.5 in.	Length 234 mm 9.2 in.	Weight 1.0 kg 2.2 lb	

TB7200 thermal barrier, for use in contact-firing processes (TB7250 is similar).

TB7250

Temp °C	200	400	600	800	
Duration (mins)	19	5.5	4.5	3.5	
Dimensions	Height 23 mm 0.9 in.	Width 165 mm 6.5 in.	Length 224 mm 8.8 in.	Weight 1.25 kg 2.8 lb	

Thermocouples

The recommended Datapaq thermocouples are ultra-fine high-temperature (PA1570) or binder-less glass-fiber (PA1144); see p. 12.

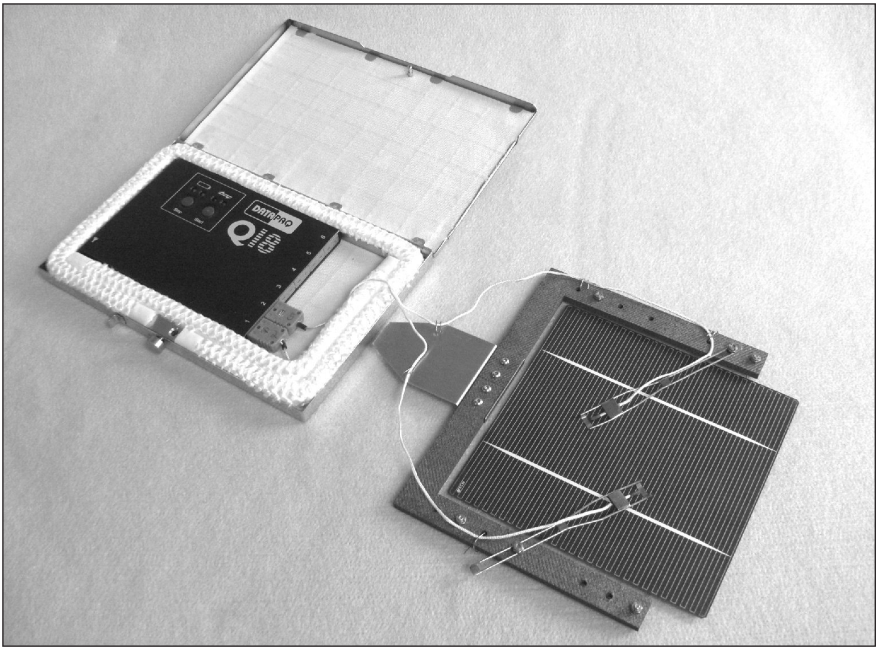
Probe Attachment

See p. 14 for general considerations.

Using the Datapaq Cell Clamp

The cell clamp PA2070 can be used with photovoltaic cells up to 156 mm square. While the cell is positioned securely, probes are held in place by the screws on the sides of the clamp. enabling the user simply to slide the associated probe-tip to the required location on the cell surface. The clamp can be used with up to four upperside probes and two underside probes.

Before use, ensure that the wires supporting the cell have been adjusted to give adequate tension: this prevents excessive bending of the cell and provides good thermal contact. When adjusting the probes, ensure that the overall width of the assembly will not foul the furnace walls or any cell guides fitted to the furnace. The thermocouple cables should be routed together back to the logger and thermal barrier in such a way as to minimize the chance of them catching on the furnace conveyor.



A SolarPaq system for use in a contact-firing process: the logger is shown in place in the open thermal barrier, and the cell clamp is holding two thermocouple probes in place on the upperside of the cell.

Attachment Without a Cell Clamp

Attaching probes to a thin cell without a clamp is very time consuming and, unless conducted with great care, will not permit repeatable results to be obtained. The most popular and effective method is to use 0.5-mm mineral-insulated probes PA1571. These need to weighted down on the furnace conveyor belt a short distance behind the cell, with the last 150 mm of the cable bent into an arc so that the cable's springiness maintains contact with the cell.

Datapaq can provide a ceramic cement that is widely used in the glass industry to attach thermocouples to flat glass. This solution does not, however, work well with photovoltaic cells because the cells are highly fragile and because the additional thermal mass of the cement will adversely affect temperature measurement.

Running a Temperature Profile

See p. 17 for general procedure.

Preparing the Logger

Select the **fastest possible sample interval** (0.05 s), as this will result in the best resolution of data during the very fast temperature ramp-up and cool-down periods.

Checking the Temperature Profile

In using Insight to analyze the profile data after downloading from the logger, ensure that you have selected 'contact firing' as the furnace type. This is best done by use of a **process file** (for detailed guidance on use of process files, press function key F1, or select Help > Contents from the menu bar, and click the section 'Process Files: Furnace, Recipe, Product'). Alternatively, set the furnace type on the Furnace tab of the Process Details dialog: click on the Insight toolbar, or select Process > Process Details from the menu.

Select the dedicated **Contact Firing analysis mode** from the tabs at the bottom of the Insight window. Other analysis modes of particular interest are:

- **Slopes** – rates of heating and cooling. You may also view the change in slope with time: select Edit > Virtual Probes, and choose 'First Derivative'.
- **Area Under Curve** – can be used as a measure of the energy absorbed by the photovoltaic cell while it is above the firing temperature.

Module Lamination

The temperature profile that the photovoltaic cell module is subjected to during the lamination process is critical to the correct curing of the EVA adhesive, and as such has a direct effect on the module lifetime. The SolarPaq system is placed into the laminator along with the sheet to be monitored, and the process can thus be monitored without disrupting normal production.

Guidance given in this chapter on using the SolarPaq system with lamination processes is additional to general descriptions of materials and procedures given elsewhere (p. 9 *and p. 17*) *and should be read in conjunction with that.*

Thermal Barrier and Frame

The thermal barrier, and the surrounding frame within which it sits, are designed not only to protect the data logger from the temperature and pressure of the lamination process, but also to ensure that no extra stress points are created on the laminator membrane.

TB7100 Thermal Barrier

For general guidance on the use and selection of thermal barriers, see p. 9.

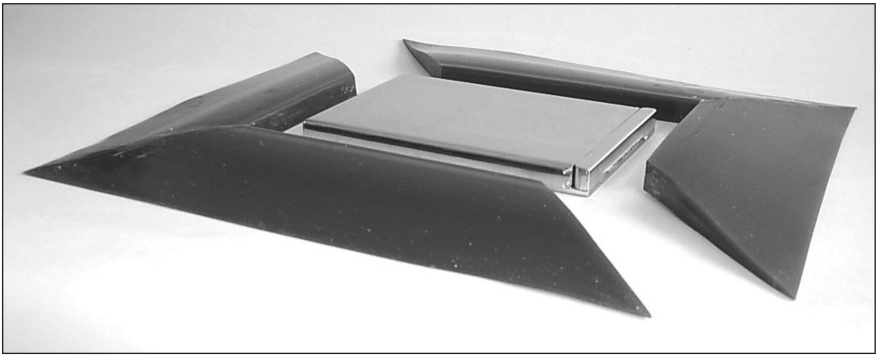
The barrier for lamination processes is designed for use with the Q18 data logger, standard 6-channel model type K (DQ1860).

Dimensions	Height 20 mm 0.8 in.	Width 147 mm 5.8 in.	Length 219 mm 8.6 in.	Weight 1.25 kg 2.8 lb

TB7150 Silicone Protection Frame

The frame is made in two sections, from silicone rubber.

Dimensions	Height 20 mm 0.8 in.	Width 365 mm 14.4 in.	Length 443 mm 17.4 in.	Weight 0.65 kg 1.4 lb



TB7100 thermal barrier, for use in lamination processes. The sections of the protection frame fit closely around the barrier.

Thermocouples

The lamination process is conducted at temperatures well below 250°C, so flexible PTFE-insulated thermocouples are recommended, e.g. PA0061 (p. 12).

Probe Attachment

The PA0060 series of thermocouples have a flattened junction and are provided with self-adhesive tape so that they can simply be stuck to the glass surface or backing membrane of the photovoltaic cell module as required. Placing the thermocouples in the center and around the edges and corners of the module enables the user to monitor the temperature across the whole module, ensuring that all points are within specification.

The thermocouple cables should be laid out in such a way that they do not cross over each other. It is recommended that the thermal barrier assembly is placed on a sheet immediately behind the test module, with thermocouples all routed back to it.

Running a Temperature Profile

See p. 17 for general procedure.

Preparing the Logger

Set the **sample interval** to 0.5 s. This will give adequate resolution of the data for a typical process duration of 10–20 minutes.

Installing the Logger in the Thermal Barrier

Slide the logger into the thermal barrier and close it, ensuring that the thermocouple cables exit through the cut-out at the base of the hinged door. The barrier should then be placed on a sheet of cardboard or glass and the silicone protection frame placed around the barrier. The thermocouple cables should pass between the protection frame and the sheet on which it is placed.

Placing the System in the Laminator

Many large laminators have an automatic loading system, and this may have to be manually overridden to enable the SolarPaq system to be placed in the loading area.

Place the instrumented module and barrier/frame assembly onto the loading belt. Ensure that the protection frame is in place, as this will protect the expensive membrane that forms the vacuum seal within the laminator.

> *Failure to position the protection frame correctly may result in damage to the laminator.*

Removing from Laminator and Downloading Data

After recovering the system from the laminator, the protection frame can be left in place; only the front section of the frame must be removed to enable the logger to be removed from the barrier.

Checking the Temperature Profile

In using Insight to analyze the profile data after downloading from the logger, ensure that you have selected 'laminator' as the furnace type. This is best done by use of a **process file** (for detailed guidance on use of process files, press function key F1, or select Help > Contents from the menu bar, and click the section 'Process Files: Furnace, Recipe, Product'). Alternatively, set the furnace type on the Furnace tab of the Process Details dialog: click on the Insight toolbar, or select Process > Process Details from the menu.

Select the dedicated **Lamination analysis mode** from the tabs at the bottom of the Insight window. Of particular interest will be analysis data on peak temperature and time spent above a user-specified temperature. The specification of the EVA adhesive being used will contain details on the cross-linking temperature and times required, and the analyses can be configured to display these and to trigger alarms if any of the probes' profiles does not meet specification.

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