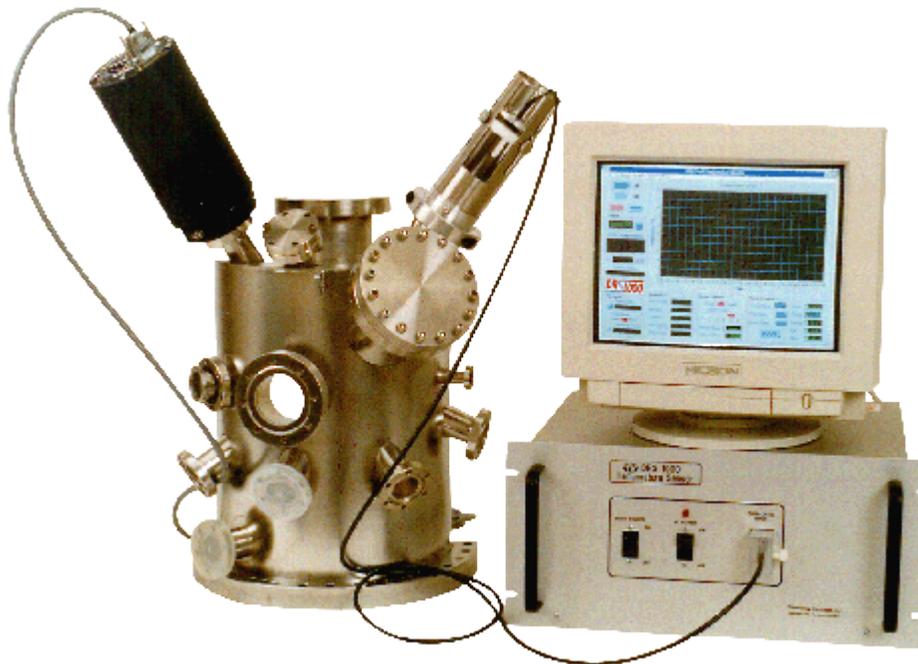


What is DRS?

DRS stands for diffuse reflectance spectroscopy. The DRS-1000 determines the temperature of a semiconductor substrate by spectroscopic analysis of diffusely reflected (or transmitted) incident white light. It is a non-contact, non-invasive, real-time temperature measurement and control device for GaAs, InP, and Si semiconductors.



[Applications / Detailed Specifications](#)
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[DRS-1000™ Components](#)

DRS-1000 is manufactured and protected under the following patent:

Patent No. 5,388,909

Date of Patent: February 14, 1995

The DRS-1000™ was developed to fulfill the need for better semiconductor wafer temperature measurement and control during processing. The two most prevalent technologies used for temperature measurement are pyrometry and the use of thermocouples.

How do they work?

Thermocouples:

Thermocouples are composed of two different types of metal wire joined at a welded junction. When two different metals are joined they generate a measurable voltage difference. This voltage depends upon the materials used and the temperature of the junction. The composition of the wires making up the thermocouples has been standardized (e.g. type K, type C, etc.) and the potential generated has been specified in standard tables. The voltages are typically very small, ranging only as high as tens of millivolts. To use them as a thermometer, the thermocouple junction must make contact with the sample and the junction voltage is measured. The voltage is compared to the reference table and the temperature deduced.

Advantages: Thermocouples are very inexpensive and compact.

Disadvantages: In order to work, the thermocouples must make mechanical contact with the sample. In cases where the sample is rotating or the sample is immersed in a hostile environment (such as harsh chemicals, plasma discharge, etc.) then thermocouples cannot be used. As well, in many cases, it is not acceptable to touch the surface of the device during processing. In addition, care must be taken to insure that the thermocouples do not conduct significant heat away from the sample.

Pyrometry:

Pyrometry is an optical technique for measuring sample temperature. The technique is based on the fact that all objects emit light over a broad range of wavelengths. The amount of light given off at a particular wavelength depends upon the temperature of the sample. An ideal object known as a black body displays a light emission curve that depends ONLY on its temperature. If one is observing a black body then measuring the emission strength at two different wavelengths is sufficient to determine its temperature. This is a relatively simple optical temperature measurement.

Unfortunately, real life objects are not ideal black bodies. If one compares the emission curve from a laboratory object to the ideal black body curve, one observes differences between the two. To compensate for the differences, a multiplicative factor, known as the emissivity, is defined.

i.e.

$$\text{Observed Emission} = \text{Emissivity} \times \text{Black Body Emission}$$

The emissivity depends upon the wavelength under observation and upon the temperature of the sample. As you can imagine, keeping track of the emissivity is essential to proper temperature measurements using pyrometry. This is a complicated task especially when the sample's surface characteristics (and, hence, emissivity) are changing during processing.

Advantages: Pyrometry is a relatively straight forward all-optical measurement technique. No contact is made with the sample and the pyrometer can be placed outside the sample chamber. The technique requires only one viewport.

Disadvantages and Limitations: The technique relies on an excellent knowledge of the emissivity of the sample and how it varies during processing to obtain an accurate measurement. Any changes in the light throughput of the sample chamber will affect the pyrometer readings. For example, if the viewport starts to cloud up, it will appear to the pyrometer that the sample is emitting less light and this will be interpreted as a decrease in the sample temperature.

In addition, because pyrometry is a passive technique (i.e. one simply collects any and all the light emitted by the sample) other sources of light in the processing environment such as heaters, plasma

discharges, heated windows, etc. each contribute to the signal collected. This can lead to significant errors in the temperature reading even if the emissivity of the sample is well characterized.

A particular problem with semiconductors is that at lower temperatures the maximum light given off by any sample occurs in the far infrared region of spectrum, with relatively little light given off in the near infrared and visible regions. (i.e. the piece of metal on your table top does not glow until it is very hot.) Unfortunately, semiconductors such as silicon, gallium arsenide, indium phosphide, and so on, are fairly transparent in the infrared region. Therefore, if one places a semiconductor sitting in front of a heater and attempts to perform pyrometric measurements in the infrared, one will primarily observe emission from the heater and not from semiconductor! This places a restriction on the design of the pyrometer -- it must observe light in the near infrared region where the sample is opaque. Since the emissions are low in this region until the semiconductor reaches a threshold temperature, pyrometry cannot be used to make temperature readings below approximately 400 - 450°C.

DRS Temperature Measurement

The DRS technique, like pyrometry, is an all-optical technique -- no contact with the sample needs to be made and the device can be placed outside the vacuum/processing chamber. A broadband, modulated light source is used to illuminate the semiconductor. Some of the light is diffusely scattered from the sample, collected and analyzed. For semiconductors, the spectra observed display a strong absorption edge which is related to the band gap of the material. As the sample temperature changes, the position of this edge (in wavelength) shifts. By calibrating the observed position of the edge with temperature, the technique can be used as a thermometer.

Advantages: No contact with the sample is required and the device can be positioned outside the vacuum/processing chamber.

Because the diffusely reflected light is scattered over a wide range of angles, the device is very flexible. It can be adapted to a large variety of sample viewing ports and geometries.

Unlike pyrometry, the DRS technique does not rely on a knowledge of the emissivity of the sample. The technique measures the optical characteristics of the sample directly and compares the results to a calibrations database. The shape of the curve is the important characteristic and not the absolute amplitude of the signal level. Therefore, clouding of the windows has a minimal effect on the temperature measurements.

Using a modulated light to illuminate the sample allows one to filter out any other sources of light that may be present in the chamber. Therefore, heater radiation, plasma discharge, or other lamps do not affect the measurements. In addition, by providing a light source rather than relying on the emissions from the sample temperature measurements can be performed from below room temperature to elevated temperatures.

Disadvantages and Limitations:

Two viewports are necessary.

The technique relies on measuring a relatively weak diffusely scattered light signal. Any process that makes the sample opaque to light renders the DRS signal too low to make accurate temperature measurements. These processes include: i) coating the sample with a metal, ii) coating the sample with an absorbing layer, iii) free carrier absorption.

Coating with an absorbing medium.

In some applications, the substrate needs to be coated with materials that have a strong absorption near

the absorption edge of the substrate. e.g. MBE growth of InGaAs on InP. In these cases, the DRS technique can perform temperature readings up to a certain thickness of the absorbing layer and then the signal level drops too low.

Free Carrier Absorption.

As a semiconductor sample heats up, more and more conductors are promoted into the conduction band. These free carriers lead to light absorption in the material. This process increases exponentially with temperature in semiconductors and renders the sample opaque above a material-dependent threshold temperature.

POTENTIAL DRS APPLICATIONS

- Semiconductor wafer temperature information (visual display; digital/analog signal output)
- MBE/CBE, MOCVD; research or production control
- MOCVD; monitoring deposition
- Reactive ion etching
- Si plasma etching
- Low temperature Si processing
- Wafer ashing
- Low temperature GaAs growth
- MBE closed loop temperature control
- Wafer temperature profiling

The DRS-1000 has been purchased by universities, corporations, and national laboratories here and abroad. Users have reported success in using it in the transmission mode (in addition to the reflectance mode). It has also been effective as the feedback sensor for substrate temperature control. Its capability for precision temperature measurement of GaAs, InP, and Si substrates up to 800°C, 700°C, and 600°C, respectively, make the DRS-1000 Temperature Sensor a uniquely powerful instrument. Its capabilities is progressing under agreements with the National Institute of Standards and Technology as well as academic and industrial institutions.

DETAILED SPECIFICATIONS

System Configuration:

The DRS-1000™ consists of a rack-mounted temperature sensor instrument cabinet, light input and collection modules which attach to process chamber view ports, and a control computer and monitor with all necessary cabling and software. All [components](#) are external to vacuum.

Temperature Range:

Calibrated materials include:

GaAs: 0-800°C

InP: 0-700°C

Si: 0-600°C

Repeatability: ±0.5°C

Accuracy: ±5.0°C

Resolution: ±0.5°C

Update Rate: ± User selectable, to <1 second

Spectrum resolution: 13 nanometers

Operating Modes:

Diffuse Reflection
Transmission

Software: Graphical user interface provides real time temperature updates and statistical data, temperature versus time, and spectrum plots. Data can be saved to ASCII test files. A RS-232 communications port allows the DRS-1000 to be controlled and monitored from a remote computer.

Reference Output:

An external analog connector provides voltages to be output as:
Type C thermocouple
Type K thermocouple
User-settable range from -5.0 to +5.0 VDC
All voltage outputs can be calibrated within the software.

Reference Input:

An external analog input connector accepts input voltages from:
Type C thermocouple
Type K thermocouple
User may set the range from -5.0 to +5.0 VDC
All voltage inputs can be calibrated within the software.

Voltage:

120 or 240 VAC
50 or 60 Hz

DRS-1000 can be used as a control device for substrate. Feedback provided in three formats:

1. RS232 communication to user computer.
2. Output voltage proportional to temperature reading.
(e.g. $V=T/100$) -5V < V < 5V range.
3. Output voltage equal to thermocouple voltage produced at temperature value. This allows the user to replace control thermocouples with DRS-1000.