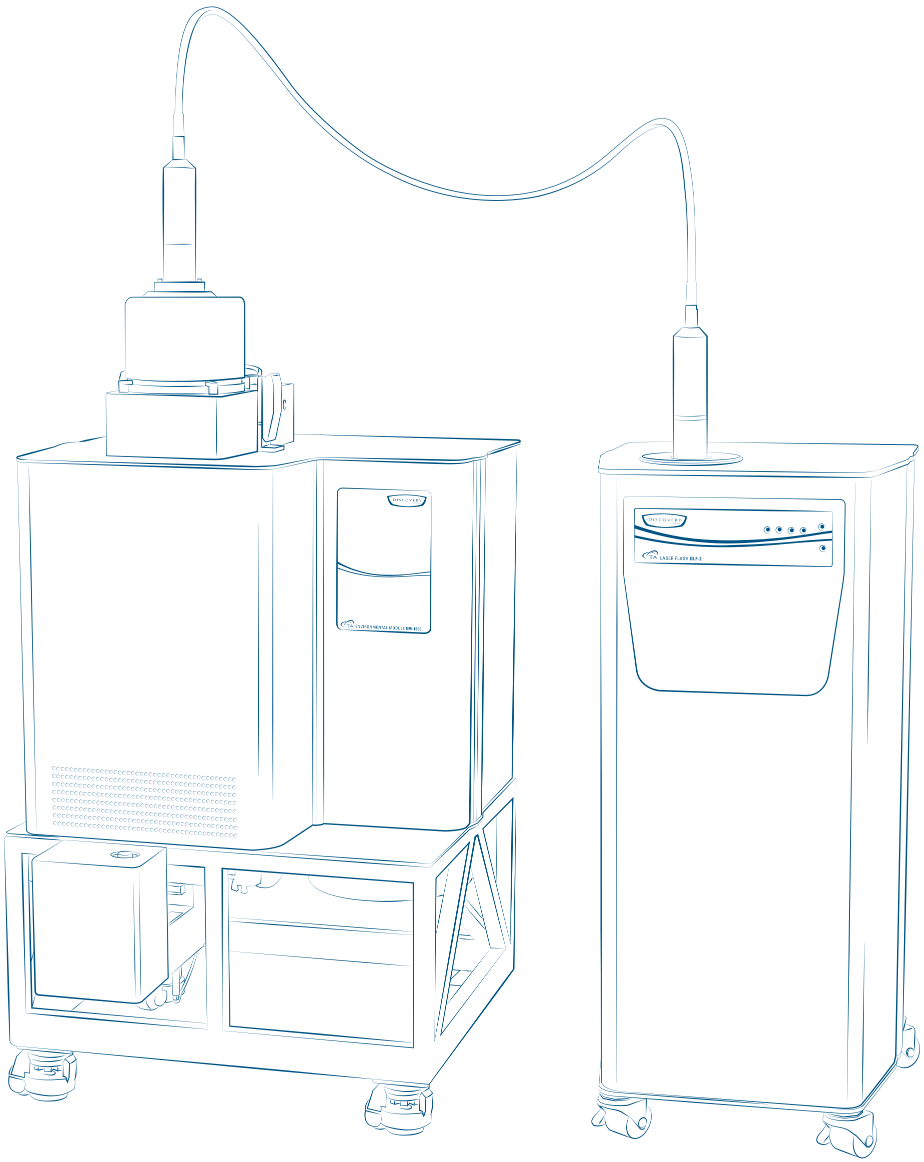
Waters™ | TA Instruments

THERMAL CONDUCTIVITY AND THERMAL DIFFUSIVITY



Discovery Light Flash Analyzers

The light flash technique provides information on a material's ability to store and transfer heat through measurements of thermal diffusivity, thermal conductivity, and specific heat capacity. Thorough understanding of these properties is critical for any process or material which experiences a large or fast temperature gradient, or for which the tolerance for temperature change is exacting. Accurate values of these properties are essential for modeling and managing heat, whether the component of interest is called on to insulate, conduct, or simply withstand temperature changes. Information about these properties is routinely used in heat transfer models of all complexities. Heat transfer property measurements also reflect important information about material composition, purity and structure, as well as secondary performance characteristics such as tolerance to thermal shock.

TA Instruments provides a full range of benchtop and floor-standing Laser and Xenon Light Flash Diffusivity Analyzers for the precise and accurate measurement of heat transfer properties of a wide range of material types and temperatures. Only Discovery Flash instruments employ unique proprietary light source, light transfer, detector, and furnace technology for the most accurate measurements by the Flash Method.

FLASH METHOD and THERMAL DIFFUSIVITY

The fundamental measurement of the Flash Method is Thermal Diffusivity, the thermophysical property that defines the speed of heat propagation by conduction: the higher the thermal diffusivity, the faster the heat propagation. As thermal diffusivity is temperature-dependent, it is usually measured over the same range of temperatures in which the material material will be required to operate. The thermal diffusivity is related to the thermal conductivity through specific heat capacity and density.

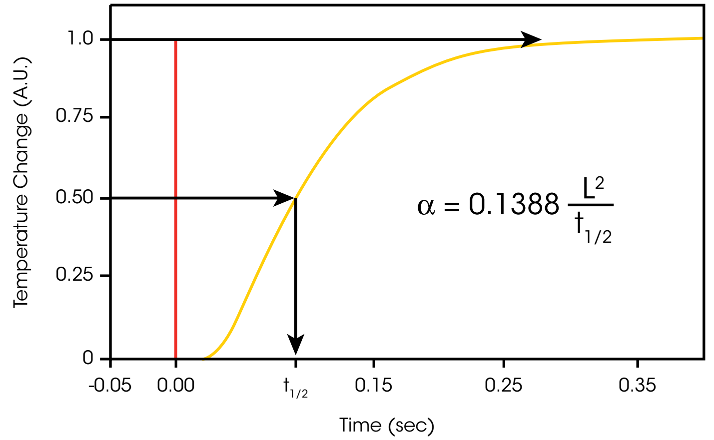
The most effective method used for measuring thermal diffusivity over a wide range of temperatures is the flash method. This transient technique is an absolute test, i.e. does not require calibration, features short measurement times, is completely non-destructive, and provides values with excellent accuracy and reproducibility. The flash method involves uniform irradiation of a specimen over its front face with a very short pulse of energy, up to the temperature range to be covered; the light source generating the pulse can be either a Xenon lamp or a laser.

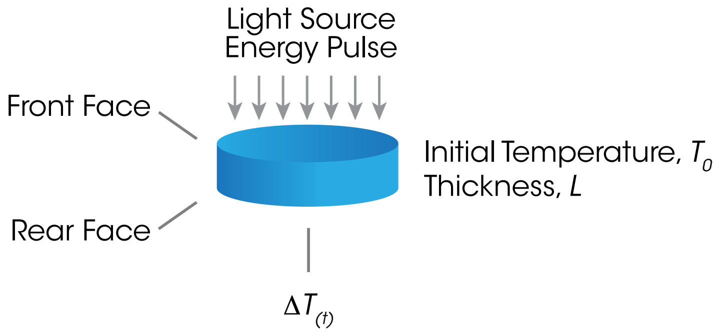
The time-temperature history of the rear face of the sample is recorded by high-speed data acquisition from a temperature detector with very fast thermal response. Based on the time-dependent thermogram of the rear face, the sample's thermal diffusivity is determined from the thickness (L) of the sample and the time the thermogram takes to reach half of the maximum temperature increase ($t_{1/2}$).

Thermal Conductivity

$$\text{Thermal Diffusivity} \quad \alpha = \frac{\lambda}{\rho \; C_p}$$

Density (ρ), Specific Heat Capacity (C_p)





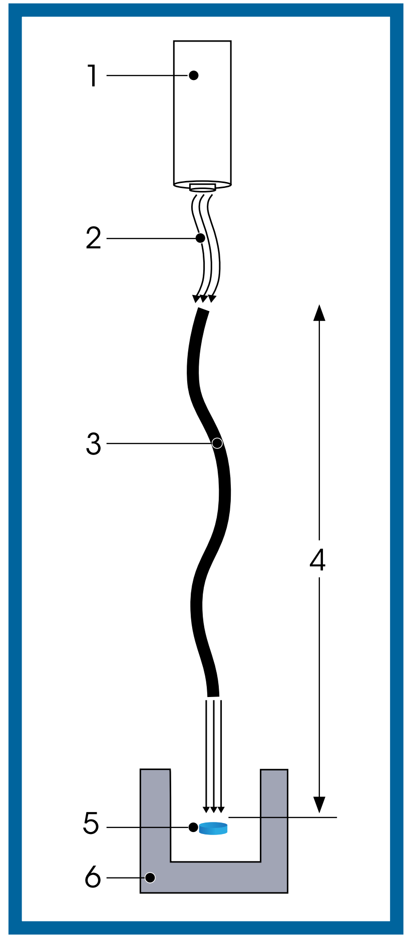
Understanding Flash Pulse Sources: Laser vs. Xenon

Only TA Discovery Flash instruments are available with choice of proprietary high-energy Laser or Xenon pulse sources. The selection of the best source for an application depends on a number of variables including sample dimensions (l,w,t), thermal conductivity, and temperature range. TA Instruments offers the widest choice of instruments with laser and Xenon sources to ensure the right solution for any application.

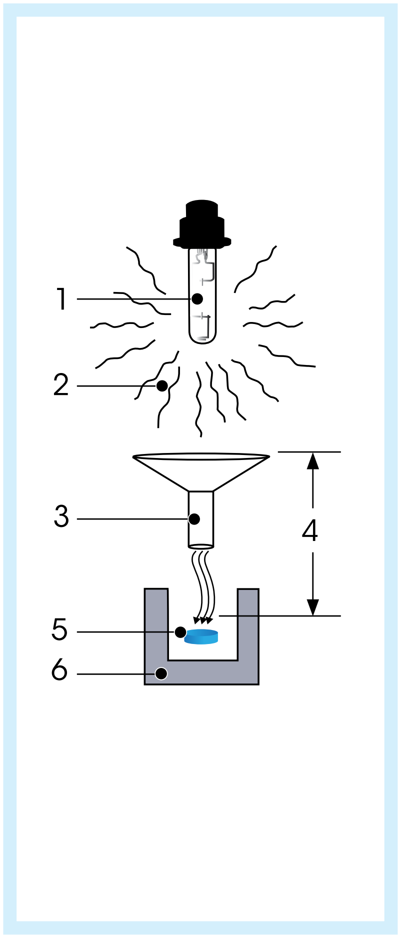
Comparison of Laser and Xenon Flash Designs

	Parameter	Laser	Xenon Light
1	Source	Monochromatic (single wavelength) Coherent (unidirectional) Collimated (parallel)	Multiple Wavelengths Diffused (multi-directional) Diverged (not parallel)
2	Light Source Energy	High to low	Medium to low
3	Pulse delivery system	Optical fiber delivers more homogeneous radiation (up to 99%)	Optical system based on lenses to collimate, focus, and deliver pulse to sample
4	Relative source to sample distance	Farther, allows higher temperatures	Closer, limits the range to moderate temperatures
5	Sample	Thin to very thick samples, materials of low conductivity, and low surface emissivity	Thin to moderately thick samples, limited by material conductivity and surface emissivity
6	Maximum Temperature	Design allows for higher, >2000˚C	Design limits to moderate temperatures, <1000˚C

Laser Flash Configuration



Xenon Flash Configuration



DISCOVERY LASER FLASH | DLF 1200

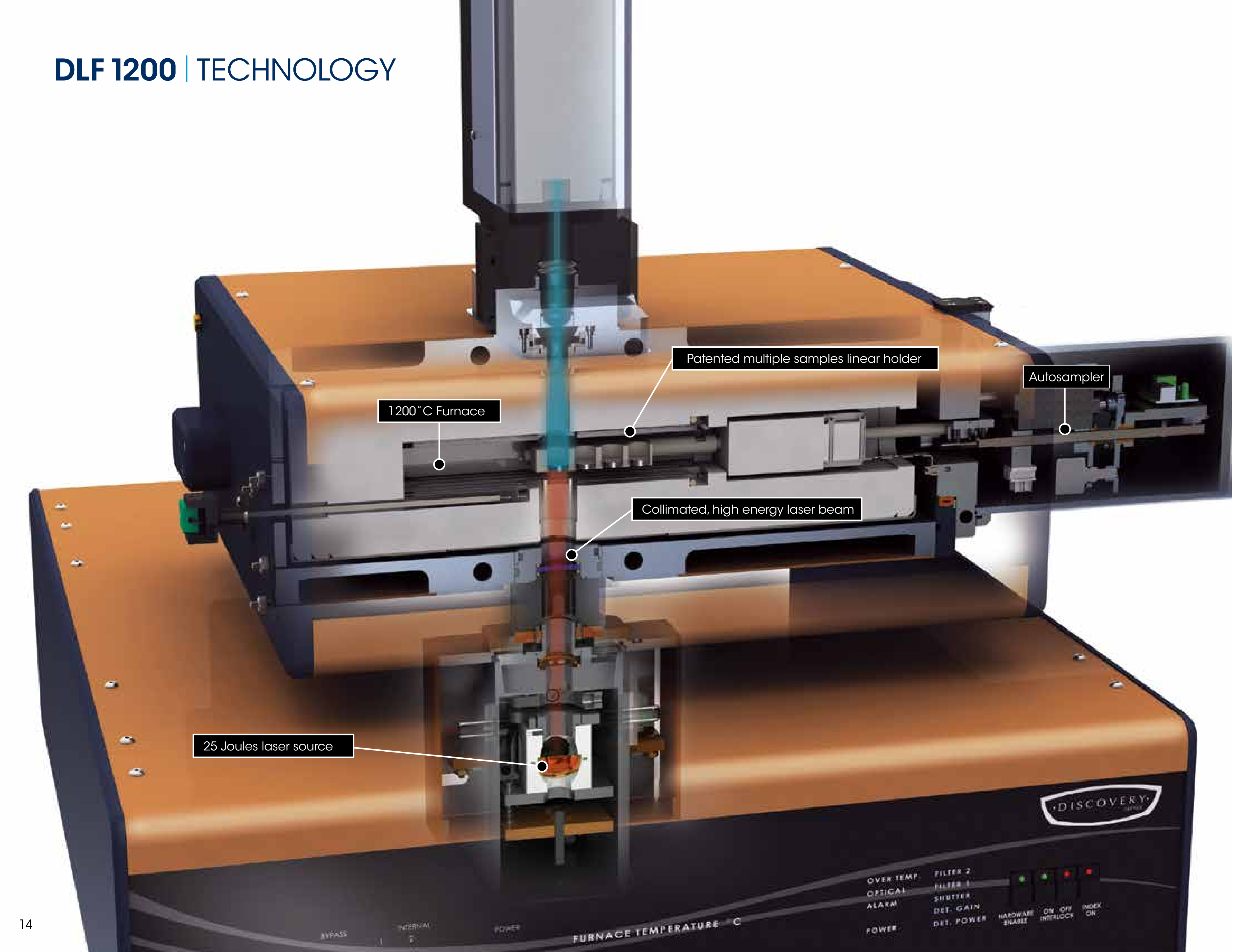
The Discovery Laser Flash DLF 1200 is a compact benchtop instrument for measurement of thermal diffusivity, thermal conductivity, and specific heat capacity of materials from room temperature to 1200˚C. It features a proprietary laser source with 17 Joules of energy for testing the widest range of samples under the most demanding conditions. Productivity is no problem with the four-sample tray design. It is the only benchtop light flash instrument available with a laser pulse source for enhanced precision, accuracy, and capabilities beyond competitive Xenon light source designs.

POWERFUL LASER FLASH
Performance in a compact
AFFORDABLE BENCHTOP DESIGN

Features and Benefits:

- Powerful laser, with 65% higher energy compared to competitive Xenon systems, for the most accurate testing of the widest range of samples, regardless of thickness and thermal conductivity to 1200˚C
- Laser is inherently coherent and precisely irradiates only the sample surface, eliminating the need to correct for lateral heat transfer from over-flash onto sample holder
- Autosampler with patented four-position alumina sample tray for maximum productivity
- Wide variety of sample trays accommodates Mullite sample sizes (up to 25.4 mm), shapes, and special fixtures (liquids, powders, laminates, films, etc.) for maximum sample testing flexibility
- Advanced resistance heated furnace provides best-in-class temperature stability and uniformity across sample from RT to 1200˚C and enables measurements in air, inert gas, or vacuum
- High sensitivity IR detector for optimum signal-to-noise ratio, delivering highest accuracy over the entire temperature range
- Real-time pulse mapping for superior thermal diffusivity of thin and highly conductive materials
- Designed to meet industry standard test methods including:
  ASTM E1461, ASTM C714, ASTM E2585, ISO 13826, ISO 22007-Part4, ISO 18755, BS ENV 1159-2, DIN 30905, and DIN EN821

Discovery Laser Flash DLF 1200



HIGH ENERGY laser source in a BENCHTOP DESIGN

High Energy Laser Source in a Benchtop Design

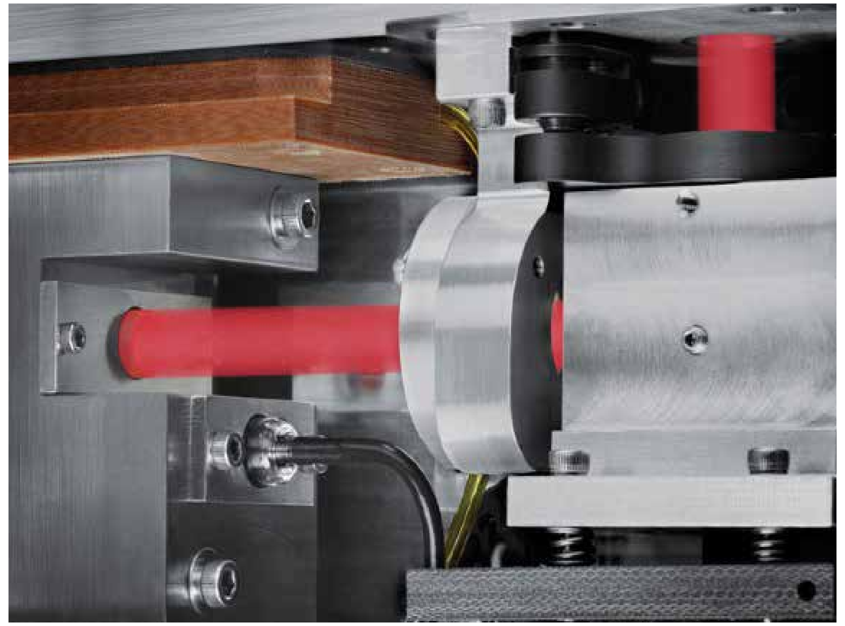
The DLF 1200 pulse source is a Class I Neodymium:Glass (Nd:glass) laser with 17 Joules of energy. It delivers an inherently collimated, monochromatic pulse to the sample surface. Designed and manufactured by TA Instruments, the safe, compact, and factory-aligned design requires no special maintenance.

65% More Energy than Xenon Flash Instrument Designs

More light pulse energy delivered to the surface of a sample during a measurement means enhanced signal quality at the detector. Only the DLF 1200 can provide 17 Joules of power providing significant benefits in a benchtop light flash design. Thicker samples, or samples of low conductivity or surface emissivity (shiny surface), are more easily tested. The higher power enables more accurate testing to 1200˚C further extending the capabilities beyond Xenon light designs.

Efficient Energy Delivery without Complex Optics

The DLF 1200 laser is in close proximity to the sample, which ensures the efficient delivery of an inherently coherent pulse to the surface of the specimen. The result is a homogeneous, high quality radiation pulse precisely focused on the sample. The design eliminates the need for complex optics to collimate and deliver light as required by Xenon light systems.



DLF 1200 Laser Delivery

DLF 1200 | TECHNOLOGY

1200˚C Furnace

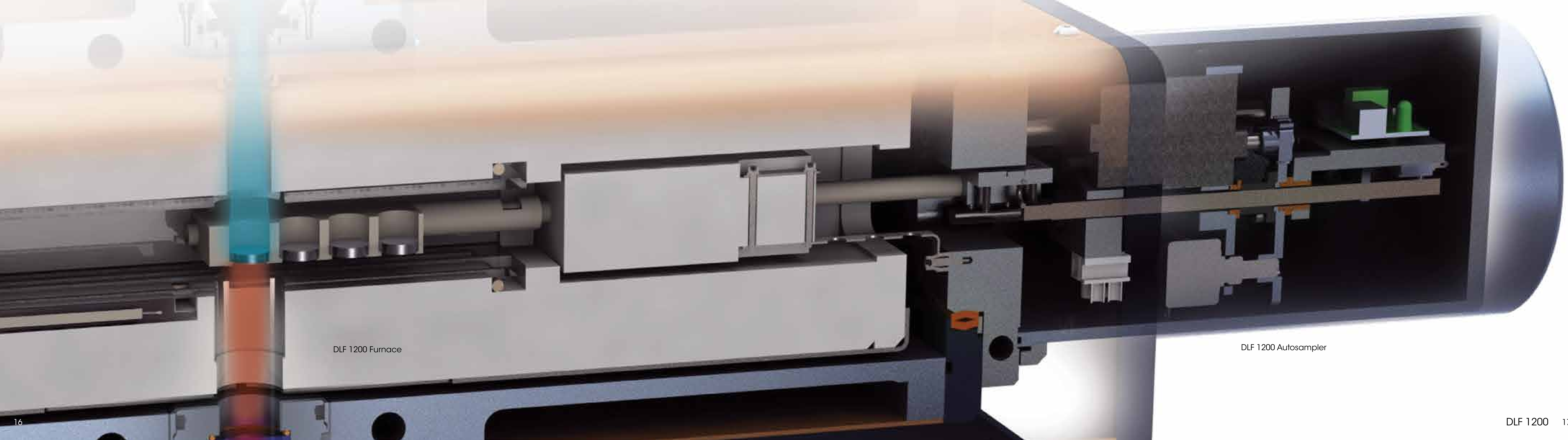
Reliable Temperature Control and Uniformity to 1200˚C

The DLF 1200 features a rugged and reliable resistance-heated furnace with superior temperature precision and uniformity. The ability of the furnace to precisely control temperature to the target value, especially at high temperatures, ensures the small 1-2 deg temperature rise due to the energy pulse is properly detected, thus providing the most accurate measurement of thermal diffusivity. The uniform heating across the entire four-position sample tray greatly improves repeatability within the same test and guarantees that unknown samples and specific heat reference standards are tested under the exact same thermal conditions for the highest quality thermal conductivity determination. The furnace can be operated in air, inert gas, or vacuum.

Reliable Automation

The DLF 1200 comes standard with a patented* linear autosampler, which greatly improves improving lab productivity. The autosampler can be configured with various sample trays that can accommodate four round or square samples up to 12.7 mm in diameter or length, or two samples up to 25.4 mm in size. Maximum sample thickness is 10 mm. In addition, application-specific fixtures for liquids, powders, laminates, and in-plane analysis for thin films and materials of very high diffusivity are available. The system offers full flexibility, enabling combinations of the various fixtures to be simultaneously loaded onto the autosampler tray.

*US Patent No. 6,375,349 B1



DLF 1200 Furnace

DLF 1200 Autosampler

DLF 1200 | PERFORMANCE DATA

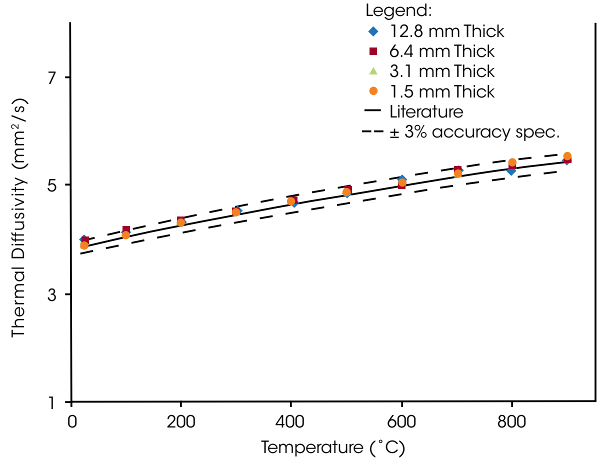
The Benefits of a Powerful Laser for Data Accuracy

Accuracy defines how close a set of measured data are to the true value. It is typically assessed by repeatedly testing the same sample under the same conditions and comparing results to reference data. For a light flash instrument, the ability to make an accurate measurement relies on all design components working together efficiently as a system. These components include the light source, the pulse delivery, the detector, and the furnace. A laser light source provides a system advantage because of the power of the light pulse. As the thickness of a sample increases, laser power is important as more energy is required to transfer through the sample and detect a temperature rise on the opposite side.

To demonstrate the superior capabilities of the DLF 1200, four samples of a very well-characterized material, stainless steel 304L, ranging from approximately 1 to 10 mm in thickness, were tested and compared to the literature values.

In the graph on the upper right, the thermal diffusivity results for the four samples are shown in comparison to the literature values for the stainless steel along with error bars of ±3% of the literature value. The accuracy is consistently better than the instrument specification of 3% for samples spanning an order of magnitude in thickness demonstrating the superior performance of the world's most powerful benchtop light flash instrument.

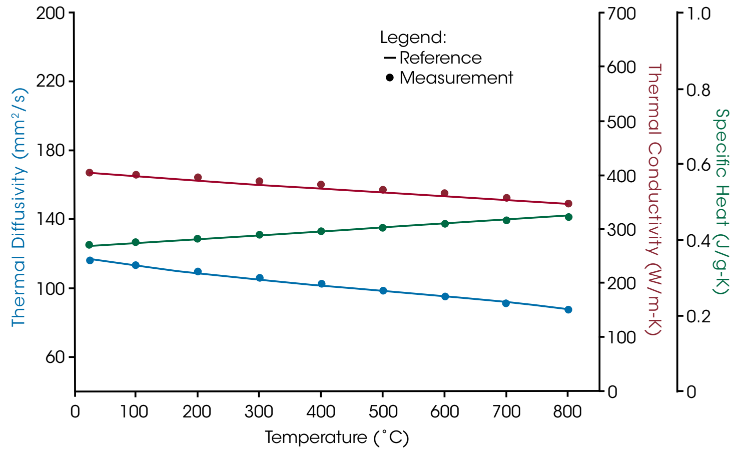
Thermal Diffusivity of 304L SS at Different Thicknesses



High Quality Thermal Conductivity

Oxygen-free high thermal conductivity copper (OFHC) is a well-characterized material typically used as a reference sample when evaluating the quality of measurements of thermophysical properties from light flash instruments. The figure on the lower right displays the thermal diffusivity, specific heat, and thermal conductivity of OFHC copper samples tested on the DLF 1200. The thermal diffusivity and specific heat results are in excellent agreement with the reference values over the entire applicable temperature range. The high quality of these results in turn provides outstanding calculated results of the thermal conductivity within 3% of the expected data.

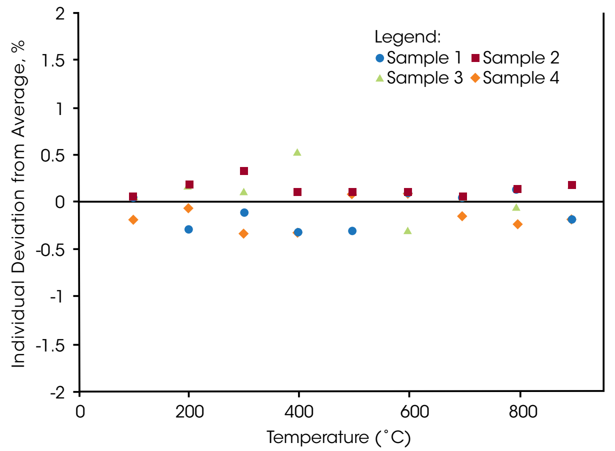
OFHC Heat Transfer Properties



Reliable Results with Patented Autosampler

When conducting flash measurements, alignment of the sample in the path of the light pulse and detector is critical for obtaining accurate results. The patented linear four-position autosampler of the DLF 1200 was designed for precision positioning of each sample in succession to ensure this condition is met. The graph to the right shows four samples of stainless steel loaded in the autosampler and tested in sequence from ambient to 900˚C. All the thermal diffusivity values are within ±0.5% of the expected value, well below the repeatability specification of ±2%. Various configurations of Autosampler trays are shown below.

Four Stainless Steel Samples Tested with Autosampler



Autosampler Tray Options

Two-Position Round Sample Tray

Four-Position Round Sample Tray

Four-Position Square Sample Tray

Four-Position Autosampler Tray

Specialty Fixtures

Laser and Xenon Light Flash instruments represent the forefront in research and development of high performance materials and the study of thermal management properties. Often, accessories with standard sizes and shapes are just not enough to test that special sample or innovative material.

In cooperation with advanced users of prestigious laboratories, TA has a range of sample holders developed specifically for the analysis of:

- Liquids
- Powders
- Pastes
- In-plane testing of thin films with high conductivity
- In-plane testing of laminates

With the ever-increasing number of new materials requiring heat transfer characterization, TA is committed to working with our customers in the development of fixtures to meet their unique testing requirements.

In-Plane

Laminate

Liquid/Powder/Paste

The Proven Software Platform for Easy, Accurate Flash Analysis Data

Functionality just one click away

All Discovery Light Flash instruments include FlashLine™ software for Instrument Control and Data Analysis. The Microsoft Windows-based software features an intuitive table-based format for simple programming of experimental parameters in the instrument control interface. Real-time monitoring allows for immediate assessment of the data quality and instrument performance during each test. The Data Analysis module's automated routines provide users with advanced analysis tools, including models for heat loss correction in both conduction and radiation.

Integrated with the pulse-shape mapping measuring system, FlashLine determines the exact shape of the laser pulse versus time to make pulse shape and width correction. It also identifies the flash zero origin and enables finite pulse effect correction which is critical to guarantee accurate measurements for thin samples and high-diffusivity materials. Additionally, the TA Instrument developed "Goodness of Fit" evaluation tool allows the user to select the best results calculated by different Thermal Diffusivity models.

Software Features:

- Unlimited temperature segments with user-defined heat ramp steps
- User-selectable laser energy for each sample at each temperature segment
- Data analysis of any already-completed segment during testing
- Determination of the specific heat by comparative method
- Option for automatic multiple-shots selection and averaging
- Correction for radiation component of transparent and translucent samples
- Automatic optimization of flash energy level
- Option for sample skip and precision criterion
- Fast zoom function for X and Y segments
- Thermal diffusivity, specific heat, and thermal conductivity tables and graphs as a function of temperature
- Calculations of all models during testing and available by the completion of testing

Standard Models Include:

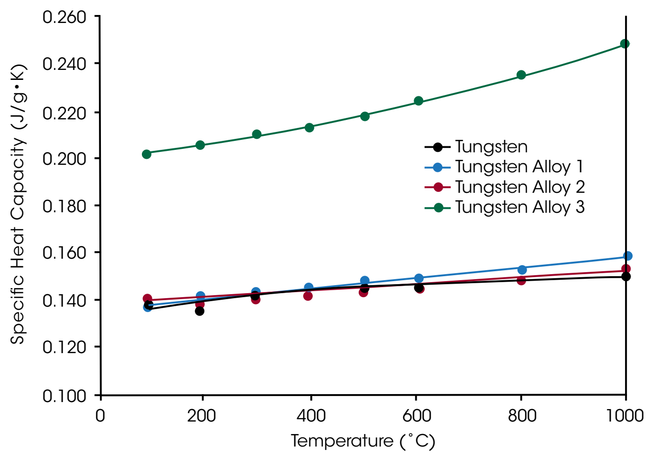
- Gembarovic for multi-dimensional heat loss correction and non-linear regression
- Goodness of Fit for the best model result selection
- Pulse gravity center to determine t_o
- Pulse length and shape correction
- Two- and three-layers analysis
- Main models: Clark and Taylor, Cowan, Degiovanni, Koski, Least Squares, Logarithmic, Moment, Heckman, Azumi, and Parker
- In-plane analysis

FLASH DIFFUSIVITY | APPLICATIONS

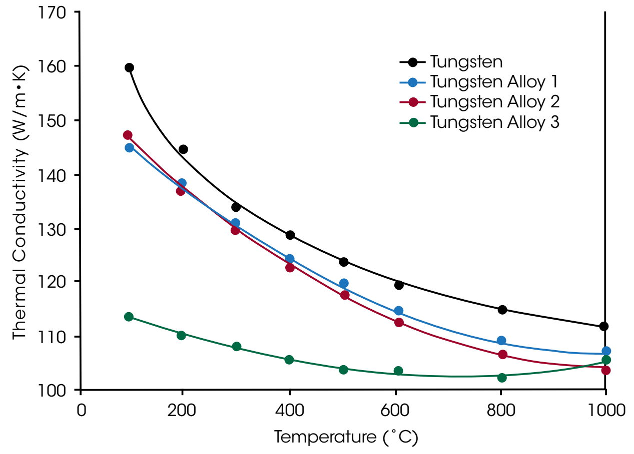
Tungsten Alloys

Tungsten alloys are valued for their high hardness, which makes them ideal for cutting or abrasion tools, and also rocket nozzles. The data to the right are the result of a study of various tungsten alloys, in comparison to a sample of pure tungsten. Thermal diffusivity and specific heat capacity data were measured on the alloy samples using a DLF 1200. The data demonstrate the variance in the heat transfer properties as a function of even subtle changes in composition. The comparison with pure tungsten data in the top figure shows Tungsten Alloy 3 has a significant deviation in the specific heat capacity value. As a result, the calculated thermal conductivity values in the bottom figure show a difference in both the absolute value as well as temperature dependence.

Specific Heat Capacity of Tungsten Alloys



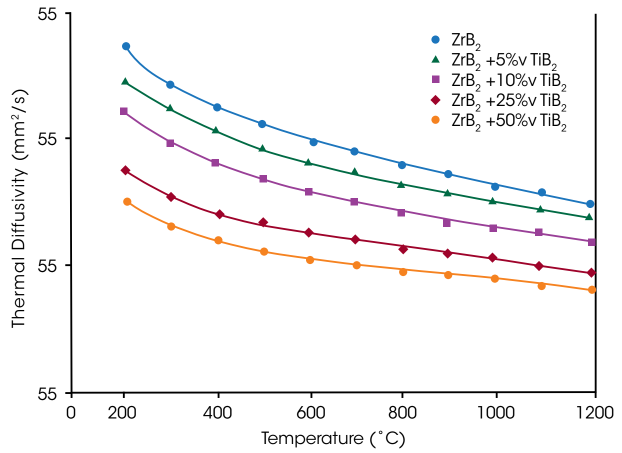
Thermal Conductivity of Tungsten Alloys



Ultra-High-Temperature Ceramics

Zirconium diboride (ZrB_2) and Titanium diboride (TiB_2) are classified as ultra-high-temperature ceramics due to their melting points in excess of 3200˚C. ZrB_2 is also remarkable for its high strength, hardness, good chemical stability and high thermal and electrical conductivities. This makes ZrB_2 an attractive option for hypersonic flight and atmospheric re-entry vehicle applications. New high-maneuverability control surfaces experience temperatures in excess of 2000˚C due to frictional heating on sharp leading and trailing edges. Knowledge of the thermal properties at high temperatures is critical to managing this heat. As seen in the plot on the upper right, increasing the solid solution content of TiB_2 in ZrB_2 decreases thermal diffusivity over the entire temperature range of the experiment, up to 1200˚C. Data was obtained using a DLF 1200.

Thermal Diffusivity of Zirconium and Titanium Diboride

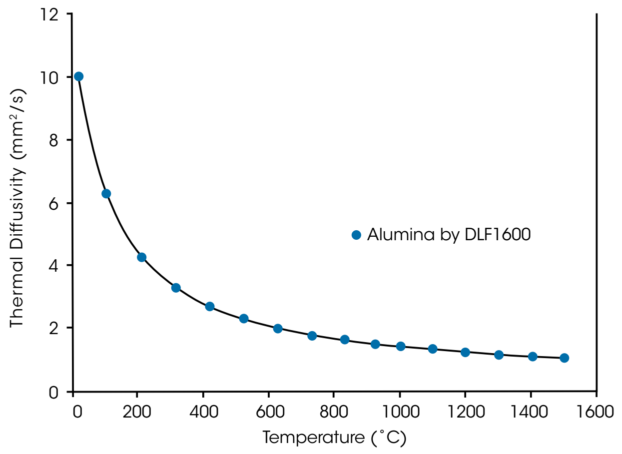


Translucent Materials

Some advanced materials are translucent to the laser flash; hence, often the samples need metal coating on both the front and rear surfaces of the sample. However, as temperature increases, the contribution of the radiative heat becomes predominant and causes a shift in the baseline of the thermogram that needs to be normalized.

The thermal diffusivity data of pure alumina material depend significantly on purity, porosity, structure, and sintering history. A pure alumina sample was measured with the DLF 1600 from room temperature to 1500˚C. The graph on the right shows the quality of resulting data after FlashLine software compensated for the baseline shift.

Translucent Materials



DISCOVERY LIGHT FLASH | SPECIFICATIONS

	DLF 2800	DLF 1600	DLF 1200
Laser Source			
Type	Class 1Nd: Glass, Floor-Standing	Class 1Nd: Glass, Floor-Standing	Class 1Nd: Glass, Benchtop
Pulse energy (Variable)	Up to 35 Joules	Up to 35 Joules	Up to 17 Joules
Pulse width	300 to 400 μsec	300 to 400 μsec	300 to 400 μsec
Proprietary Transfer Optics	Fiber Optic Wand	Fiber Optic Wand	Optic Beam Guide
Furnace			
Sample Temperature Range	RT to 2800˚C	RT to 1600˚C	RT to 1200˚C
Atmosphere	Inert, vacuum (50 mTorr)	Air, inert, vacuum (50 mTorr)	Air, inert, vacuum (50 mTorr)
Detection			
Thermal Diffusivity Range	0.01 to 1000 mm^2/s	0.01 to 1000 mm^2/s	0.01 to 1000 mm^2/s
Thermal Conductivity Range	0.1 to 2000 W/(m*K)	0.1 to 2000 W/(m*K)	0.1 to 2000 W/(m*K)
Data Acquisition	16 bit	16 bit	16 bit
Accuracy			
Thermal Diffusivity	± 2.3%	± 2.3%	± 2.3%
Thermal Conductivity	± 4%	± 4%	± 4%
Repeatability			
Thermal Diffusivity	± 2.0%	± 2.0%	± 2.0%
Thermal Conductivity	± 3.5%	± 3.5%	± 3.5%
Sample			
Round	8, 10, 12.7 mm Diameter	8, 10, 12.7, 15.9 mm Diameter	8, 10, 12.7, 25.4 mm Diameter
Square	8, 10 mm Length	8, 10 mm Length	8, 10, 12.7 mm Length
Maximum Thickness	10 mm	10 mm	10 mm
Autosampler			
Maximum Thickness	Six-Position Carousel	Five-Position Carousel	Four-Position Linear Tray

	DXF 900	DXF 500	DXF 200+
Flash Source			
Type	Xenon, Benchtop	Xenon, Benchtop	Xenon, Benchtop
Pulse energy (Variable)	Up to 15 Joules	Up to 15 Joules	Up to 15 Joules
Pulse width	400 to 600 μsec	400 to 600 μsec	400 to 600 μsec
Proprietary Transfer Optics	Light pipe beam guide	Light pipe beam guide	Light pipe beam guide
Furnace			
Sample Temperature Range	RT to 900˚C	RT to 500˚C	-175˚C to 200˚C
Atmosphere	Air, inert, vacuum (50 mTorr)	Air, inert, vacuum (50 mTorr)	Air, inert, vacuum (50 mTorr)*
Detection			
Thermal Diffusivity Range	0.01 to 1000 mm^2/s	0.01 to 1000 mm^2/s	0.01 to 1000 mm^2/s
Thermal Conductivity Range	0.1 to 2000 W/(m*K)	0.1 to 2000 W/(m*K)	0.1 to 2000 W/(m*K)
Data Acquisition	16 bit	16 bit	16 bit
Accuracy			
Thermal Diffusivity	± 2.3%	± 2.3%	± 2.3%
Thermal Conductivity	± 4%	± 4%	± 4%
Repeatability			
Thermal Diffusivity	± 2.0%	± 2.0%	± 2.0%
Thermal Conductivity	± 3.5%	± 3.5%	± 3.5%
Sample			
Round	8, 10, 12.7, 25.4 mm Diameter	8, 10, 12.7, 25.4 mm Diameter	8, 10, 12.7, 25.4 mm Diameter
Square	8, 10, 12.7 mm Length	8, 10, 12.7 mm Length	8, 10, 12.7 mm Length
Maximum Thickness	10 mm	10 mm	10 mm
Autosampler			
Type	Four-Position Linear Tray	Four-Position Linear Tray	Twelve-Position Carousel

* High Vacuum Option: 0.5 mTorr with turbo pump

Industry-Leading Sales & Support

TA Instruments' leadership position results from the fact that we offer the best overall product in terms of technology, performance, quality, and customer support. While each is important, our demonstrated commitment to after-sales support is a primary reason for the continued loyalty of our customers. To provide this level of support, TA Instruments has assembled the largest worldwide team of field technical and service professionals in the industry. Others promise good service. Talk to our customers and learn how TA Instruments consistently delivers on our promise to provide exceptional service.

With direct support staff in **24 countries** and **5 continents**, TA Instruments can extend its exceptional support to you, wherever you are.

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