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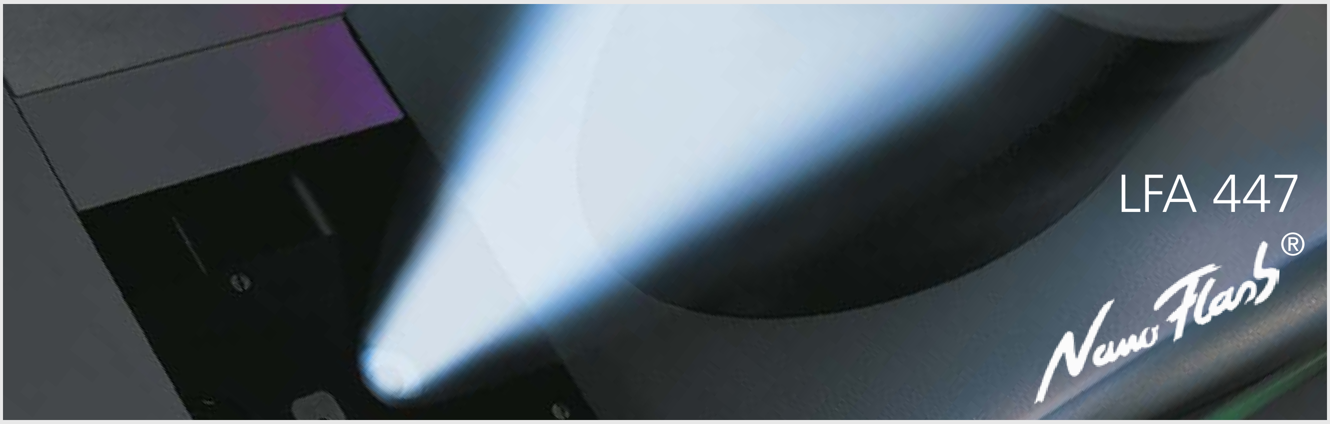
Analyzing & Testing

Thermal Diffusivity – Thermal Conductivity

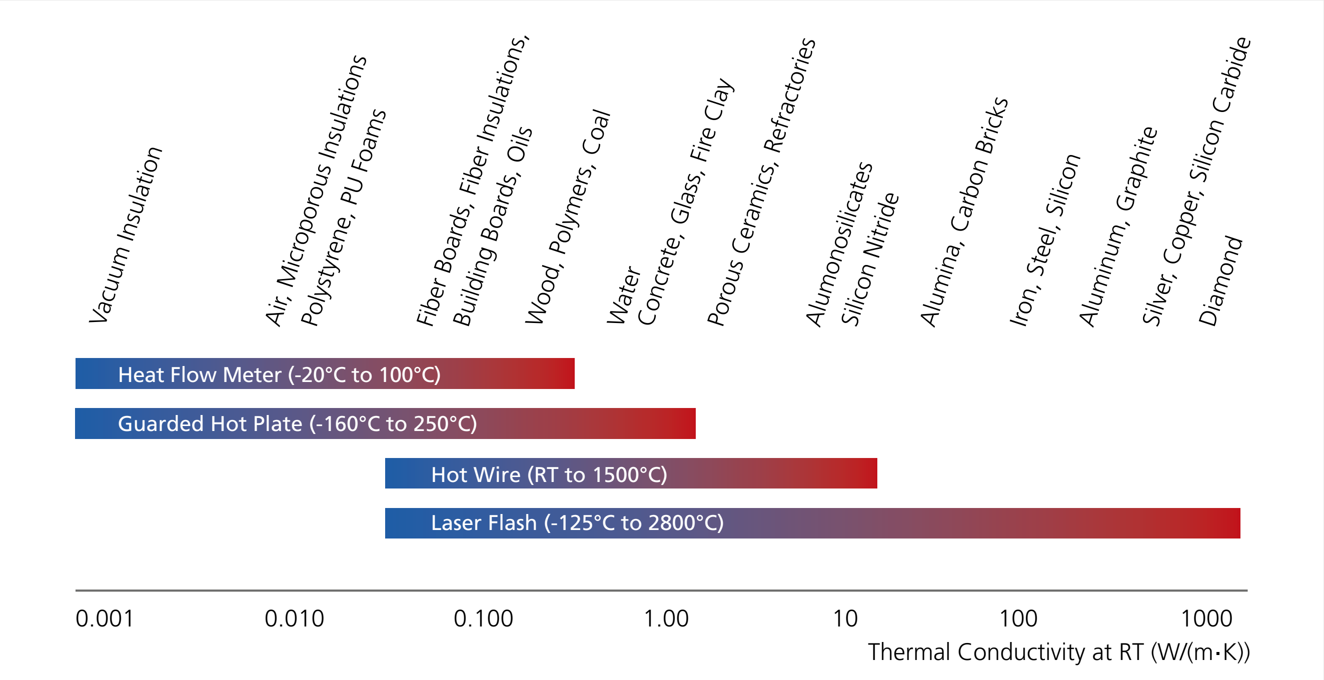
Method, Technique, Applications



Leading Thermal Analysis

LFA 447 *NanoFlash®*

What is the heating/cooling load of a building as a function of the weather conditions and how can I improve it? How can I improve the heat transfer out of an electronic component? What are the optimum materials and how do I design a heat exchanger system to achieve a required efficiency? In order to answer questions like these, material properties such as thermal diffusivity and thermal conductivity must be known. Engineers must select from a variety of test methods to characterize the diverse array of materials and configurations they employ in their designs. For ceramics, metals, composites, and multi-layer systems, the flash technique is an ideal choice. Easy sample preparation, fast testing times, and high accuracy are only some advantages of this non-contact test method. NETZSCH offers a variety of flash systems to cover a broad range of applications and temperatures from -125°C up to 2800°C. The NETZSCH *NanoFlash®* system is designed as a cost-effective, easy-to-operate, highly accurate instrument for testing between room temperature and 300°C.



For the measurement of low conductivity materials such as insulations, NETZSCH offers a broad selection of Heat Flow Meters and Guarded Hot Plate Instruments. For the analysis of refractory materials, a hot wire system (TCT 426) is available. Differential scanning calorimeters (DSC 404 ***F1/F3*** *Pegasus®*) for the measurement of specific heat, and dilatometers (DIL 402 C series) for the analysis of density and length changes up to high temperatures, are also available.

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Flash Apparatus LFA 447 *NanoFlash*®

The NETZSCH LFA 447 *NanoFlash*® is based on the well-known flash method. In this method, the front side of a plane-parallel sample is heated by a short light pulse. The resulting temperature rise on the rear surface is measured using an infrared detector. By analysis of the resulting temperature-versus-time curve, the thermal diffusivity can be determined.

The LFA 447 *NanoFlash*® is a powerful research tool for making accurate, rapid thermal diffusivity tests on small specimens. It can complete tests on dozens of samples at room temperature in a single morning or make measurements at temperatures up to 300°C automatically.

Fast Test Times

The speed and repeatability of thermal diffusivity measurements have made this technique the method of choice among researchers worldwide, replacing traditional steady-state methods that are difficult, costly, and much slower. By measuring thermal diffusivity (a) of a material, its thermal conductivity (λ) can be determined if specific heat (c_p) and density (ρ) are known.

Advanced Data Analysis

The evaluation of the measured data can be done using the well known half-time method:

$$a = 0.1388 \cdot \frac{d^2}{t_{1/2}}$$

d = sample thickness

The *NanoFlash*® system additionally allows the consideration of radial and facial heat losses and finite pulse effects using advanced mathematical regression routines.
Using the multiproperty measurement capabilities of the *NanoFlash*®, both thermal diffusivity and specific heat can be determined simultaneously – on the same specimen – thus yielding thermal conductivity if the density is known:

$$\lambda(T) = a(T) \cdot c_p(T) \cdot \rho(T)$$

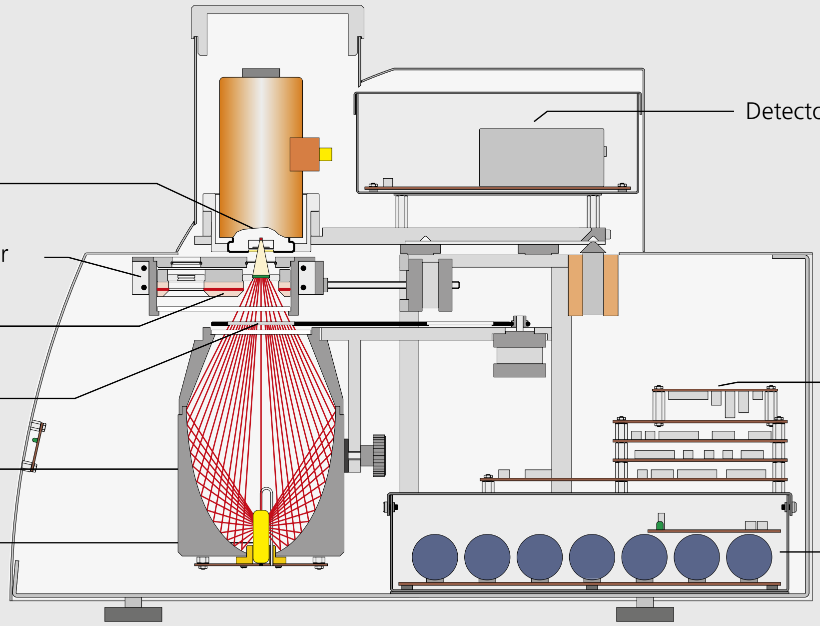
Standardized Test Method

The *NanoFlash*® works according to national and international standards such as ASTM E1461, DIN EN 821, DIN 30905 and ISO 22007-4:2008.

MTX-Version

A special version with a matrix system (MTX) allows scanning of surfaces (50 mm x 50 mm) for analysis of the thermal diffusivity over the area. This enables the detection of structural inhomogeneities or defects under the surface.

System Setup – Software



In the LFA 447 *NanoFlash*®, a state-of-the-art technology is integrated in a compact measuring system. The flash lamps, sample, and detector are vertically arranged. Therefore the use of mirrors is not necessary. Short signal pathways and a good signal-to-noise ratio are thereby warranted.

The Flash Lamp

A high-performance Xenon flash lamp is applied to produce the heat pulse on the front of the sample. The lamp is placed in a parabolic mirror, whereby a large part of the radiation given off is focused on the sample. The assembly of the mirror and the position of the lamp are conceived such that a homogenous illumination of the entire sample surface is warranted. The energy released from the flash lamp can be adjusted using the software (voltage and pulse length). The pulse width is adjustable between 0.06 ms and 0.3 ms.

Sample Placement

The samples are placed in an automatic sample changer which can test up to four samples in one test. The samples are thereby brought into a special sample carrier which can be adjusted according to the user's wishes. There are standard carriers for testing of round samples with e.g., 10 mm, 12.7 mm or 25.4 mm diameter. Sample receptacles for the testing of square samples (e.g. 8 mm x 8 mm or 12.7 mm x 12.7 mm) also exist (special sample holder sizes on request).
The measurement of the sample temperature is done with a temperature sensor which is integrated into the system's sample holder plate. Special sample holders are available for the measurement of liquids and pastes with unmatched accuracy and test speed.

The Furnace

The system is equipped with a furnace for temperature-dependent measurements up to 300°C. The furnace is directly integrated into the sample changer of the system, whereby a small thermal mass and thereby fast heating and cooling times are secured.

The Detector

The measurement of the temperature increase on the rear of the sample is carried out with a liquid-nitrogen-cooled InSb (Indium-Antimonide) infrared detector. The non-contact measurement of the temperature increase guarantees an easy sample change and a short response time for the signal acquisition system. Both the detector and amplifier components are designed for measurements with data acquisition rates of 500 kHz.

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Software

The LFA 447 *NanoFlash*® run under *Proteus*® software on a Windows® operating system. It combines easy handling and complex evaluation routines, thus offering a solution to almost every application challenge.

Software Features

- Multitasking: simultaneous measurement and evaluation
- Full network compatibility
- Easy printout and export of measuring curves and data (ASCII)
- Selectable screen design by means of docking windows
- Multi-moduling: operation of several different instruments with one computer
- Integrated data base

Measuring Tasks

- Full control of the sample changer
- Easy and user-friendly input of test parameters
- Free selection of temperature programs (heating, coding)
- Automatic optimization of the system parameters (measuring time, amplification, etc.)
- Automatic evaluation of the measurement after each shot with selected evaluation model

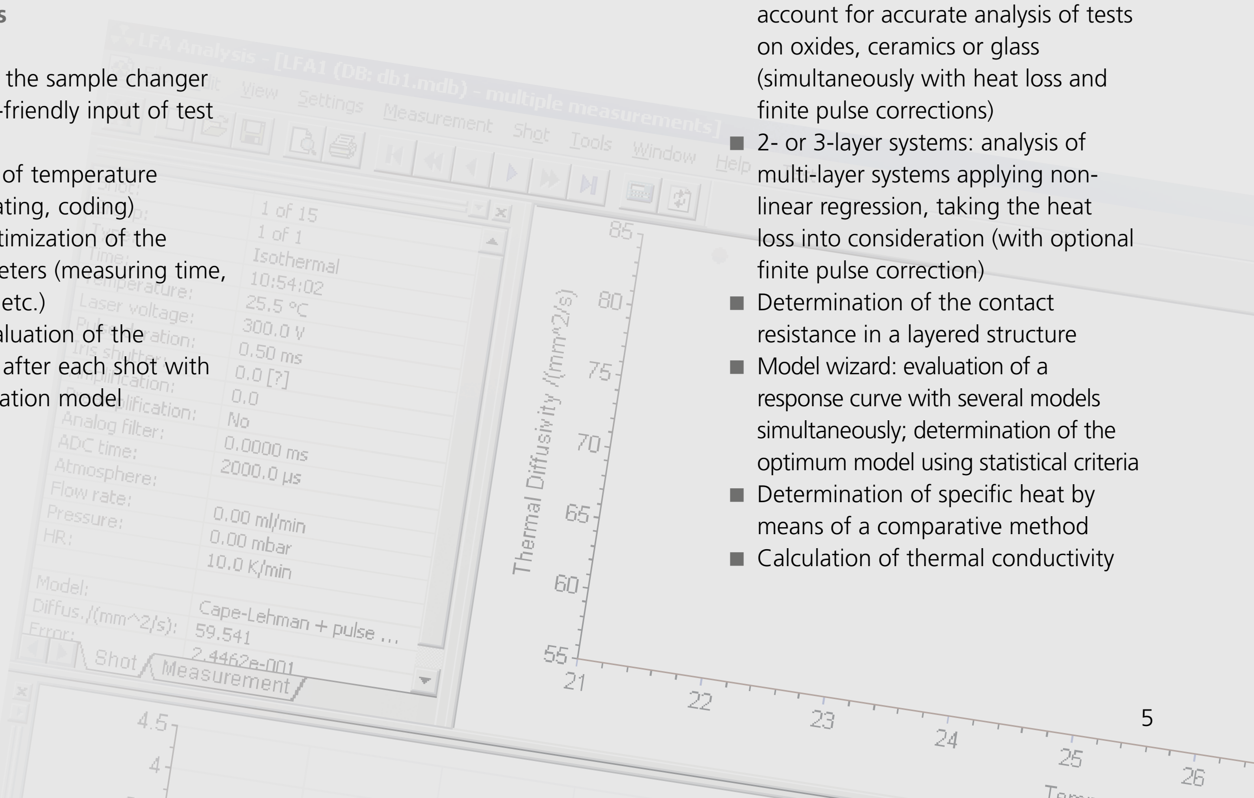
Evaluation Tasks

- Presentation of an individual response curve, the entire result as well as test parameters and measured values in one presentation
- Free input or import of density and specific heat values for determination of thermal conductivity
- Simultaneous presentation of thermal diffusivity and conductivity data in one plot
- Storage and restoration at any point of the analysis
- Presentation and new evaluation of data from previous measurements

Evaluation Models

More than 20 different models representing state-of-the-art technology are available to the user. These have been developed in cooperation with leading experts from science and industry:

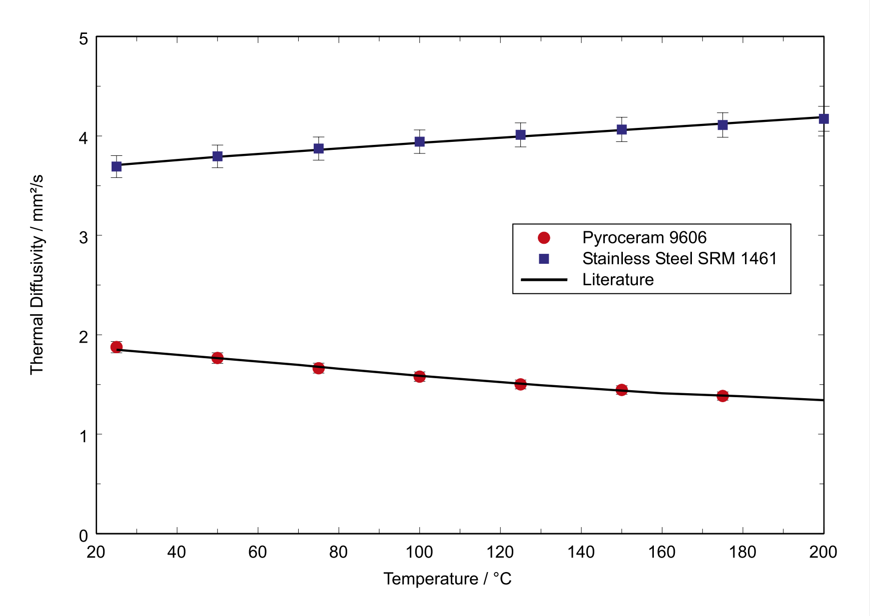
- Accurate (patented) finite pulse correction
- Standard adiabatic analysis
- Standard heat loss corrections in accordance with Cowan, Clark and Taylor
- Cowan-Fit: non-linear regression based on Cowan's publication (incl. finite pulse correction)
- Improved Cape-Lehmann model: non-linear regression taking radial and facial heat losses into consideration
- Correction of radiation effects: radiation effects are taken into account for accurate analysis of tests on oxides, ceramics or glass (simultaneously with heat loss and finite pulse corrections)
- 2- or 3-layer systems: analysis of multi-layer systems applying non-linear regression, taking the heat loss into consideration (with optional finite pulse correction)
- Determination of the contact resistance in a layered structure
- Model wizard: evaluation of a response curve with several models simultaneously; determination of the optimum model using statistical criteria
- Determination of specific heat by means of a comparative method
- Calculation of thermal conductivity



LFA 447 *NanoFlash*® for a Wide Variety of Applications

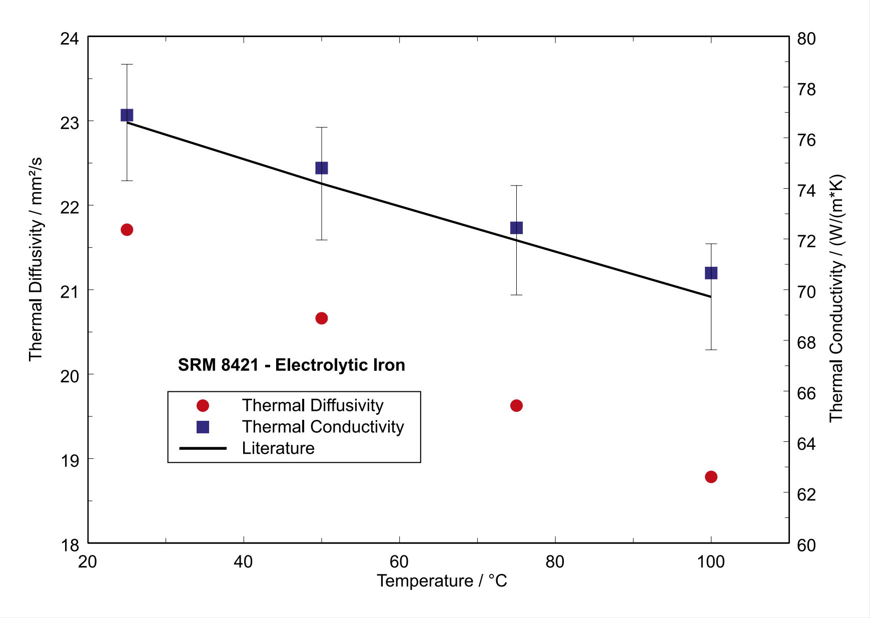
Performance – Stainless Steel and Pyroceram 9606

The thermal diffusivities of two well-known standard materials (NIST SRM 1461 Stainless Steel and Pyroceram 9606) were measured versus temperature with the LFA 447 *NanoFlash*®: The figure shows the measurement results as compared to literature values (Touloukian et al., 1970, Henderson et al., 1998) up to 200°C. It can clearly be seen that the deviations between the literature values and the measurement results are less than 3% (error bars). This demonstrates the high accuracy of this flash unit in the field of metals and ceramics.



Accuracy – NIST SRM 8421 Electrolytic Iron

A certified NIST thermal conductivity reference material (SRM 8421) was measured between room temperature and 100°C. Additionally shown are the NIST values for the thermal conductivity for this material together with the stated accuracy (3%). As expected, both the thermal diffusivity and thermal conductivity decrease with temperature. It can be seen that the determined thermal conductivity values are close to the NIST values. The measured deviations are within the stated uncertainty range for this certified standard reference material.



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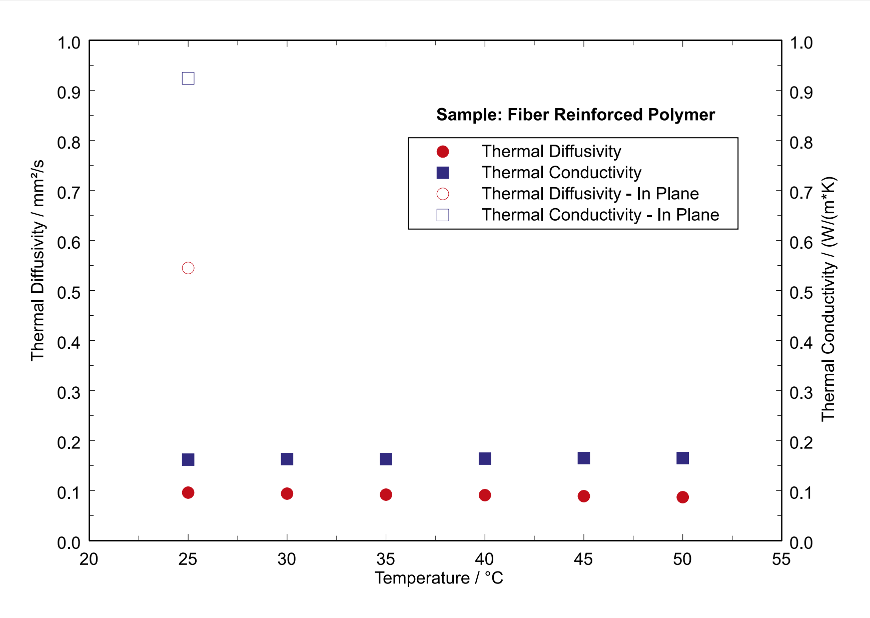
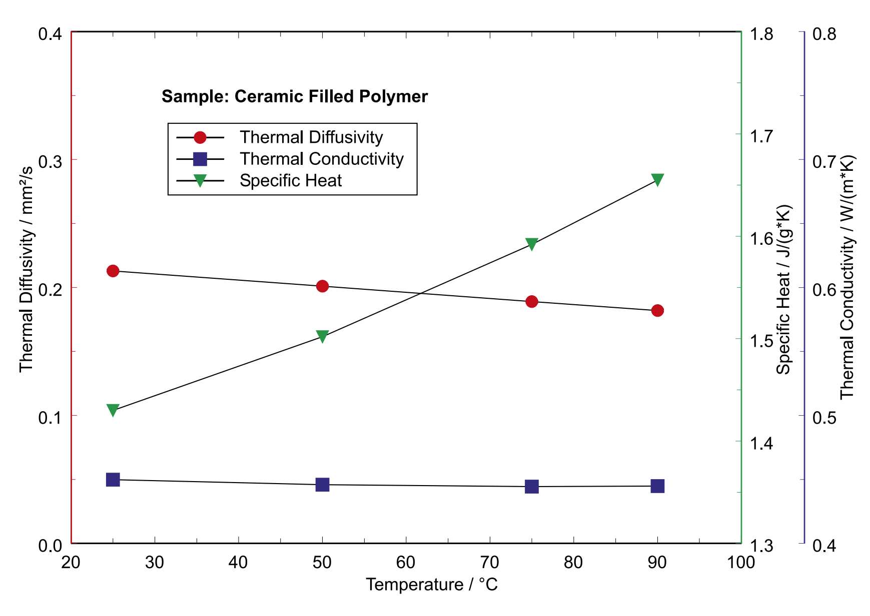


In-Plane Tests – Fiber-Reinforced Epoxy

More and more polymers, metals or ceramics are being reinforced with fibers to improve their bending strength and to adjust them to special applications. In many cases, the fiber reinforcement results in a high degree of anisotropy to the mechanical and thermal transport properties. By employing special sample holders, the flash technique allows analysis of this anisotropy in the thermal diffusivity and thermal conductivity. The measurement example clearly demonstrates that the values for both the thermal diffusivity and thermal conductivity, perpendicular to the fiber direction are significantly lower than the results of the in-plane test (in the fiber direction).



Thermal Conductivity Determination – Polymer Tape

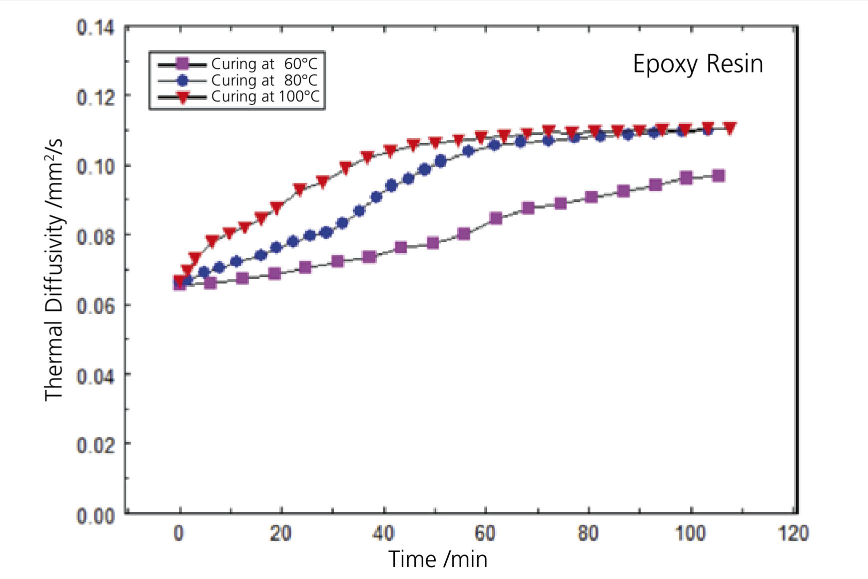
The LFA 447 *NanoFlash*® allows easy and fast temperature-dependent measurement of the thermal diffusivity. Additionally, the specific heat can be determined by employing a comparative method. A direct determination of the thermal conductivity is possible, if the bulk density of the material is known. This method was used for the thermo-physical properties charaterization of a polymer tape between room temperature and 90°C. The calibration standard for the specific heat determination was Pyroceram 9606. It can clearly be seen that both the thermal diffusivity and specific heat changed significantly versus temperature. The resulting thermal conductivity depicts nearly no temperature dependence.

Specialties – Technical Key Data

Measurement of Low-Viscosity Liquids – Curing of an Epoxy Resin

For the determination of the thermal diffusivity of liquids, special containers are required to keep the sample in the right position and shape during an experiment. A sample holder specially designed for that purpose is displayed below. It consists of parts from stainless steel and a PEEK ring and allows time- and cost-reduced measurements with high precision.

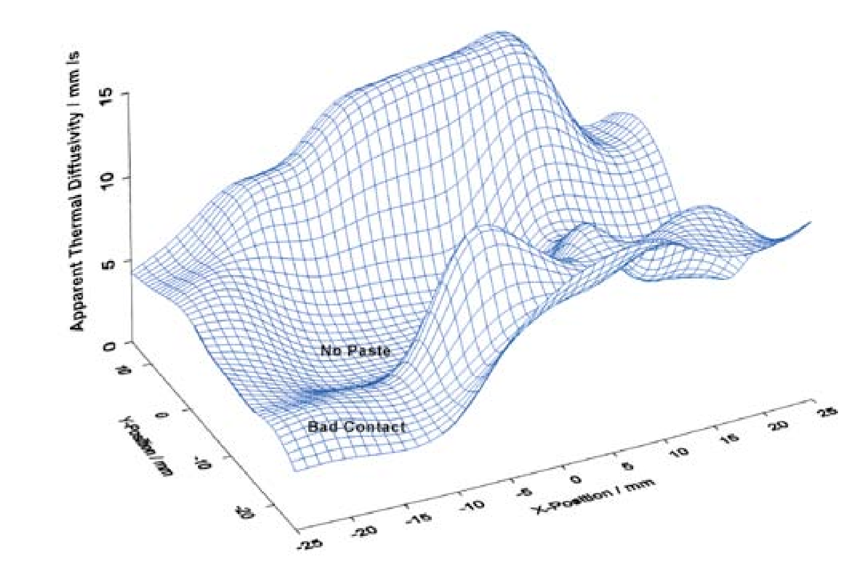
Sample holder for low-viscosity liquids



The graphic presents the test results of an epoxy resin at curing temperatures of 60°C, 80°C and 100°C. In all cases, the thermal diffusivity rises with time. Whereas the increase at 60°C is nearly constant, the thermal diffusivity shows a stepwise gain at 80°C and 100°C. For both curing temperatures, the final thermal diffusivity values are identical after approx. 100 min and the level is significantly higher than for 60°C.

MTX-Results

The result shows the influence of a thermal conductivity paste between two aluminum plates. In the areas of poor contact or missing paste, values were obtained in the apparent thermal diffusivity, which were very low. The areas of good contact appear as high values in the apparent thermal diffusivity. Such an analysis can be carried out without disassembling of the composite system.



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Technical Key Data

Standard Sample Size	up to 25.4 mm (1") diameter, or 6 mm / 8 mm / 10 mm / 12.7 mm square, up to 3 mm (0.12") thick, specials on request
Temperature Range	Ambient to 300°C
MTX Version	Scanning range: 50 mm x 50 mm, resolution: down to 0.1 mm; operation at room temperature
Thermal Diffusivity Range	0.01 mm^2/s to 1000 mm^2/s
Thermal Conductivity	0.1 W/(m·K) to 2000 W/(m·K)
Repeatability *)	Thermal Diffusivity: ±2% Specific Heat: ±3%
Accuracy	Thermal Diffusivity: ±3% Specific Heat: ±5%
Flash Source	Xenon Flash Lamp, wavelength: 150 nm to 2000 nm Pulse Energy: up to ≈10 Joules (selectable by voltage and pulse length)
Sensor Type	IR Detector (InSb) with integrated dewar
Utilities	115 V or 230 V - 50/60 Hz, 15 A - Controller Distilled Water (approx. 0,5L / month) Liquid Nitrogen (only during measurements, approx. 1l/h)
Instrument Dimensions (LxWxH)	61 cm x 56 cm x 43 cm

*) based on tests on standard materials

Additional Information

www.netzsch.com/lfa447

Expertise in Service

Our Expertise – Service

All over the world, the name NETZSCH stands for comprehensive support and expert, reliable service, before and after sale. Our qualified personnel from the technical service and application departments are always available for consultation.

In special training programs tailored for you and your employees, you will learn to tap the full potential of your instrument.

To maintain and protect your investment, you will be accompanied by our experienced service team over the entire life span of your instrument.

Summary of Our Services

- Installation and commissioning
- Hotline service
- Preventive maintenance
- Calibration service
- IQ /OQ/PQ
- On-site repairs with emergency service for NETZSCH components
- Moving/exchange service
- Technical information service
- Spare parts assistance

Our Expertise – Applications Laboratories

The NETZSCH Thermal Analysis Applications Laboratories are a proficient partner for nearly any thermal analysis issue. Our involvement in your projects begins with proper sample preparation and continues through meticulous examination and interpretation of the measurement results. Our diverse methods and over 30 different state-of-the-art measuring stations will provide ready-made solutions for all your thermal needs.

Within the realm of Thermal Analysis and the Thermophysical Properties Testing, we offer you a comprehensive line of the most diverse analysis techniques for materials characterization (solids, powders and liquids).

Measurements can be carried out on samples of the most varied of geometries and configurations. You will receive high-precision measurement results and valuable interpretations from us in the shortest possible time. This will enable you to precisely characterize new materials and components before actual deployment, minimize risks of failure, and gain decisive advantages over your competitors.

For production problems, we can work with you to analyze concerns and develop solutions. The minimal investment in our testing and services will reward you with reduced down time and reject rates, helping you optimize your processes across the board.

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The NETZSCH Group is an owner-managed, internationally operating technology company headquartered in Germany.

The three Business Units – Analyzing & Testing, Grinding & Dispersing and Pumps & Systems – provide tailored solutions for highest-level needs. Over 2,500 employees at 130 sales and production centers in 23 countries across the globe guarantee that expert service is never far from our customers.

When it comes to Thermal Analysis, Adiabatic Reaction Calorimetry and the determination of Thermophysical Properties, NETZSCH has it covered. Our 50 years of applications experience, broad state-of-the-art product line and comprehensive service offerings ensure that our solutions will not only meet your every requirement but also exceed your every expectation.

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