

NETZSCH

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LFA 427
-70...2000°C

Laser Flash Apparatus LFA 427 for the measurement of thermal diffusivity

Due to the ever-increasing number of materials being used in high-temperature applications, knowledge of their thermophysical properties, especially thermal conductivity, is of paramount importance.

One of the most widely used methods for determining thermal conductivity is to measure the thermal diffusivity (a), specific heat (c_p) and density (ρ) as a function of temperature, and then to compute the thermal conductivity from these data. That is: $\lambda(T) = a(T) \cdot \rho(T) \cdot c_p(T)$.

By far the most popular and widely used instrument for measuring thermal diffusivity is the laser flash apparatus. It has been estimated that this technique is used in over 80% of thermal diffusivity measurements conducted worldwide. Compared with the direct measurement of thermal conductivity, the advantages

of this non-contact, non-destructive method are simple sample geometry, easy sample preparation and small sample size, as well as applicability for a wide range of diffusivity values and excellent accuracy and reproducibility. Also, because very little time is needed for a single measurement, a wide range of temperatures can be covered in a short period of time.

NETZSCH-Gerätebau in Selb has developed a Laser Flash Apparatus (LFA 427) for the accurate determination of the thermal diffusivity of materials over a wide temperature range.

The LFA 427 is an entirely new concept which has resulted in a unique instrument. The completely enclosed system with its compact and space-saving design meets the highest safety requirements (laser class 1). No additional safety precautions are necessary.

The design (vertical alignment of laser output and IR detector) allows simple, horizontal insertion of the sample. Also, the short distances involved minimize the loss of laser energy and energy impinging upon the IR detector. Measurements can be carried out in a static or dynamic oxidizing or inert gas atmosphere or under vacuum.

The user-friendly 32-bit-MS®-Windows™ (pull-down menus, on-line help, etc.) permits both manual and fully-automatic control of the experimental procedure as well as the evaluation of the experimental data. The data can be corrected for heat loss or finite pulse time using any number of mathematical models. Further, the evaluation of 2- and 3-layer samples and of the contact resistance between layers is possible.

Summary:

The NETZSCH LFA 427 is a modern analysis instrument:

- user-friendly
- accurate
- safe (laser class 1)
- diffusivity range:
0.001 ... 10 cm²/s
- temperature range:
-70 ... 2000°C.

Its software combines the knowledge and experience gained over the past 30 years by specialists working in this field.

The NETZSCH Program also offers a high-temperature DSC 404 C Pegasus® for the measurement of the specific heat. This instrument is also capable of measuring transformation energetics, etc. to a high degree of accuracy at temperatures up to 1650°C (specific heat to 1500°C).

The temperature-dependent density and length change can be determined by using one of the NETZSCH Series 402 Dilatometers.



LFA 427 (2000°C-Version)

Principle

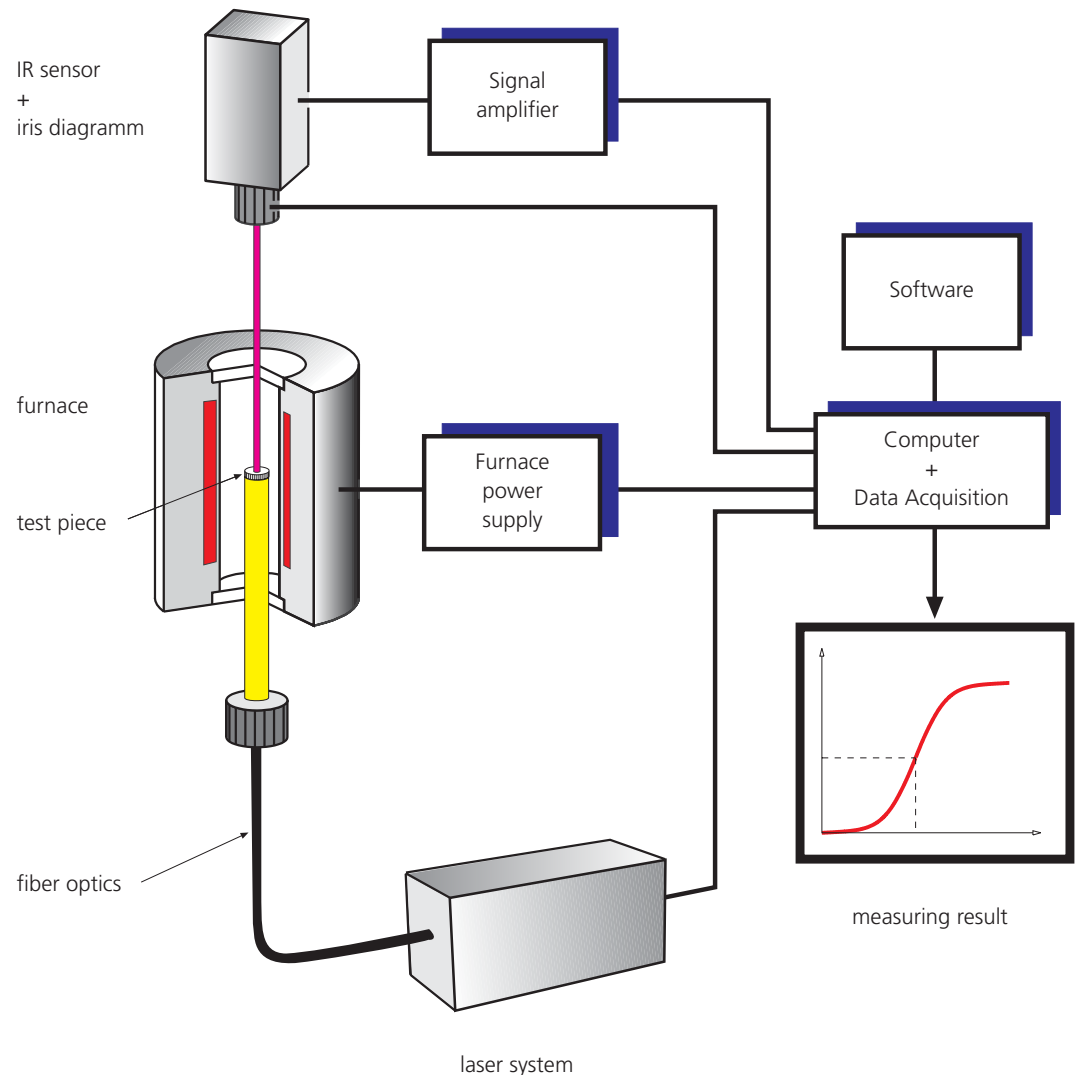
The sample is mounted on a carrier system which is located in a furnace. After the sample reaches a predetermined temperature, a burst of energy emanating from a pulsed laser is absorbed on the front face of the sample, resulting in homogeneous heating. The relative temperature increase on the rear face of the sample is then measured as a function of time by an IR detector. The thermal diffusivity is computed

by the software using these time/relative temperature increase data. For adiabatic conditions, a is determined by the simple equation

$$a = 0.1388 \frac{l^2}{t_{0.5}}$$

where
 l = sample thickness (mm)
 $t_{0.5}$ = time (s) at 50% of the temperature increase.

The elegance of the method lies in the fact that the troublesome measurement of the absolute quantity of laser energy absorbed by the sample and of the resulting absolute temperature increase is replaced with a more accurate and direct measurement of time and relative temperature increase.



Hardware Concept

The LFA 427 consists of four essential components:

- measuring unit with furnace, sample carrier and IR detector
- controller for measuring unit
- laser system connected via fiber optics
- data acquisition system and computer.

The vertically-constructed measuring unit is the primary component of the system. The laser system is connected with the measurement part by a sheeted glass fiber. The beam emerges from the outlet of the fiber optics.

A recipient block is located above the laser optics. The tube-shaped sample holder and its adjusting device are mounted on this block. A toggle quick seal permits a vacuum/gas-tight coupling between the recipient block and the furnace. The furnace system is raised and lowered by means of a motor-driven hoist.

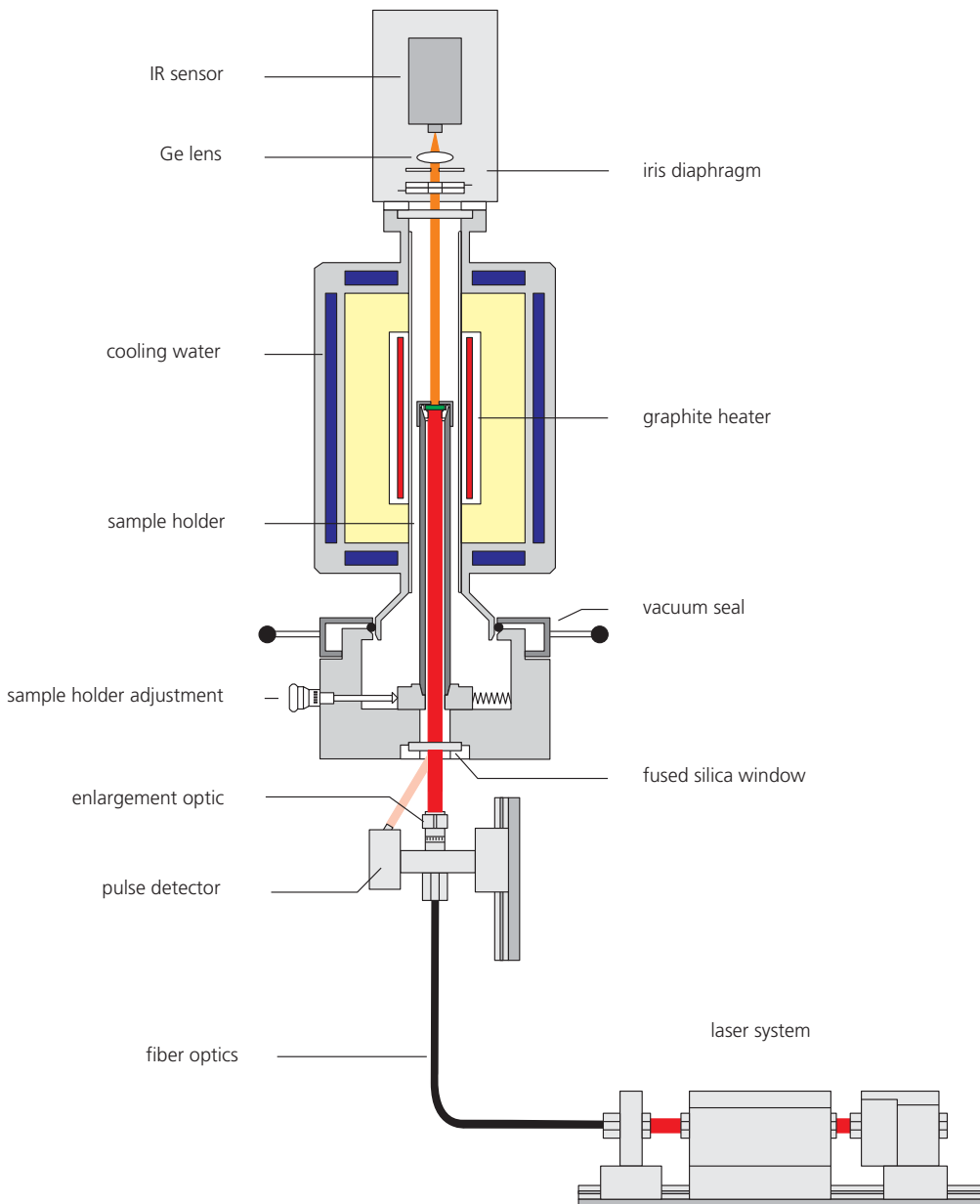
A solid-state laser produces a pulse with the energy which is required for the flash method. The emission wave length of 1064 nm is in the infrared range. The pulse width of

the laser is variable.

A thermocouple measures the absolute temperature of the sample. This thermocouple is mounted laterally on the sample carrier tube at the same height as the sample. Different thermocouples can be used, depending on the temperature range of interest.

An IR detector measures the temperature increase on the rear face of the sample. The indium antimonide or mercury cadmium telluride detectors are liquid nitrogen cooled. Further features of this detectors are the germanium lens, which also acts as a filter for the laser light, and a motor-driven iris diaphragm.

With regard to safety requirements, this is a "laser class 1" instrument. This means that the apparatus need not be housed in a separate room, nor do laser safety glasses need to be worn by the operator. These requirements have been eliminated with the completely enclosed design of the measuring unit and with a safety system electronically connected to both the hoist and front door of the cabinet. This safety system closes the shutter of the laser system immediately if the hoist is moved or the front door opened, thus preventing release of the laser pulse.



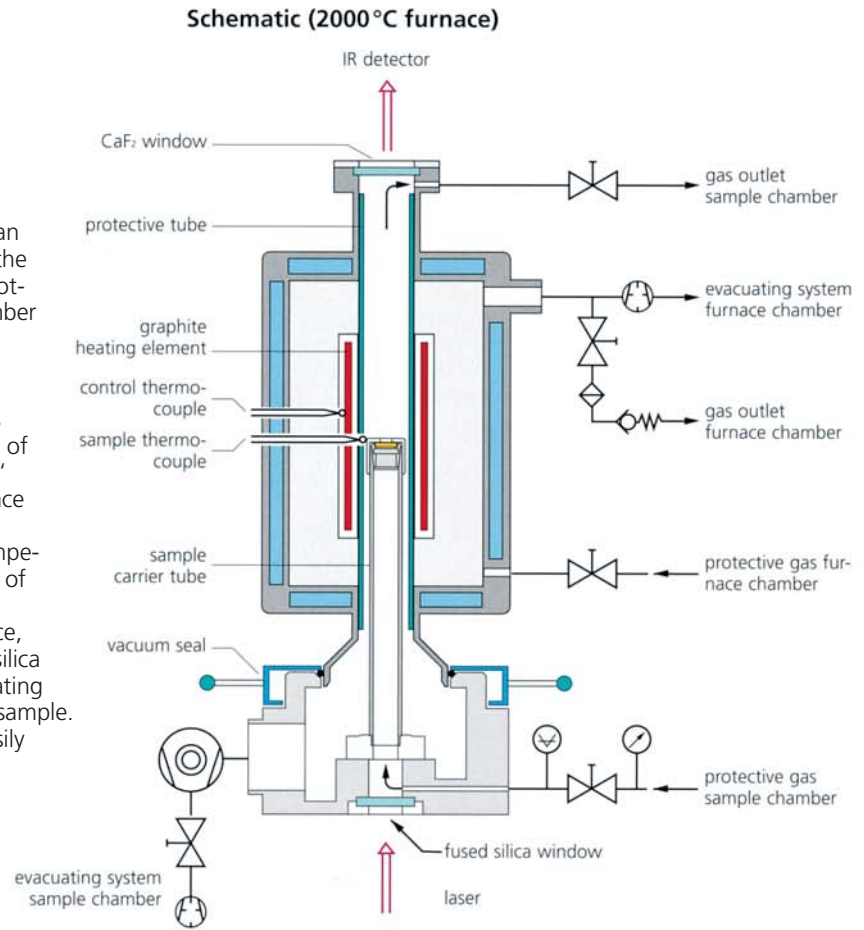
Hardware Schematic (2000°C furnace)

Furnaces

The LFA 427 can be equipped with different furnaces. A liquid nitrogen cooled furnace allows tests between -70 and 400°C. A forced air-cooled SiC furnace enables tests between room temperature and 1550°C.

The 2000°C furnace consists of a graphite heating element and graphite insulation mounted in a water-cooled housing. The furnace and sample chambers are separated by an Al₂O₃ (1700°C max. temperature). The Al₂O₃ tube allows measurements to be conducted under high vacuum or in static or dynamic inert gas or oxidizing atmospheres, while the glass carbon tube allows measurement under high vacuum or in static or dynamic inert gas atmospheres.

The different furnaces can easily be exchanged by the operator. The top and bottom of the sample chamber are sealed by calcium fluoride and fused silica windows, respectively. The IR detector, which is mounted directly on top of the furnace, has "visual" contact with the back face of the sample, allowing measurement of the temperature increase. The end of the fiber optics, located directly under the furnace, fires through the fused silica window, resulting in heating of the front face of the sample. The windows can be easily removed for cleaning.



Sample Holder Systems

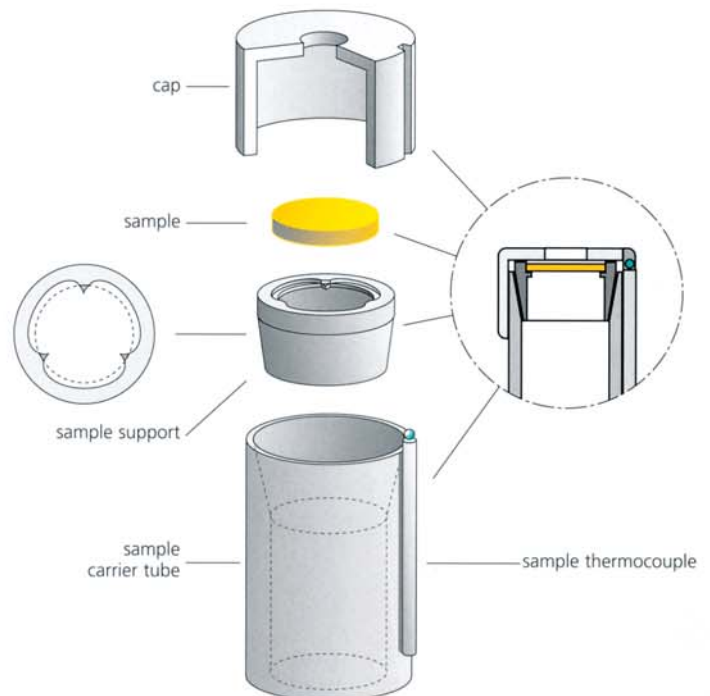
The vertical design of the measuring unit allows very easy sample handling. The sample is in a horizontally stable, well-defined position. Once the furnace has been raised and swung to the side, the sample is directly accessible and can be easily inserted or removed.

An Al₂O₃ or graphite sample carrier tube mounted in a metallic adjusting socket carries the sample support, sample and sample cap. The sample support is mounted directly in the cone-shaped opening of the carrier tube. The sample support holds and centers the sample on 3 "teeth". This design minimizes the contact between the sample and sample support, thereby reducing heat loss and allowing uniform laser irradiation of

almost the entire sample surface. The inside diameter of the sample support is constructed as a limiting diaphragm below the sample and corresponds exactly to the diameter of the sample. The impinging laser beam with a larger diameter is masked exactly to the sample diameter.

A cap, which is placed over both the sample and sample holder, prevents the laser energy from impinging directly on the detector. This prevents detector damage as well as signal disturbance.

Sample holders for smaller samples, square samples, laminates, liquid metals, slags or fibers can be employed at the sample support.



Sample holder system

Software

The LFA 427 comes equipped with a 32 bit MS®-Windows™ software package, especially tailored to the needs of our users. It combines easy handling and complex evaluation routines, thus offering a solution to almost every problem the user might face.

More than 15 different evaluation models available for the user, have been developed with leading experts from science and industry and correspond to current requirements and state-of-the-art technology.

Software Features

- 32 bit MS®-Windows™-software: fully compatible with other MS-Windows™ programs
- 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 Task

- easy and user-friendly input of test parameters
- free selection of temperature programs with heating, isothermal and cooling segments
- temperature calibration: a unique tool for calibration of the sample thermocouple by the user is introduced
- manual or automatic optimization of the system parameters (measuring time, amplification, etc.)
- automatic recording and storage of the laser pulse for each shot for an optimum finite pulse correction
- automatic evaluation of the measurement after each shot with one or several evaluation models

Evaluation Task

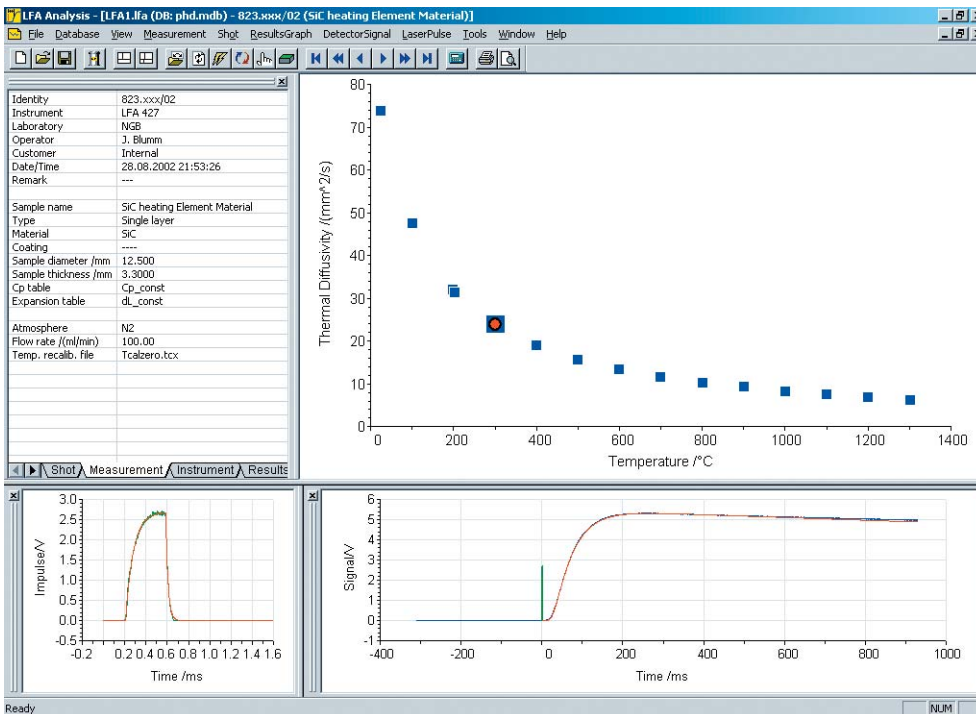
- presentation of an individual response curve, the entire result as well as test parameters and

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

- accurate finite pulse correction based on the corresponding laser pulse
- standard heat-loss corrections: correction models according to Cowan, Clark and Taylor, and Degiovanni known from literature, are integrated
- Cowan-Fit: non-linear regression based on the original publication by Cowan (optionally with or without finite pulse correction)
- Cape-Lehmann-model is improved. Non-linear regression with consideration of radial and facial heat losses (optionally with or without finite pulse correction)
- correction of radiation effects: a new model that considers radiation effects is integrated for accurate analysis of tests on oxide ceramics or glasses (simultaneously with heat-loss and finite pulse corrections)
- 2- or 3-layer systems: analysis of multi-layer systems with consideration of the heat loss based on non-linear regression (optionally with or without finite pulse corrections)
- contact resistance: determination of the contact resistance in a layer system
- model wizard: simultaneous evaluation of a response curve with several models; determination of the optimum model using statistic criteria
- determination of specific heat by means of a comparative method

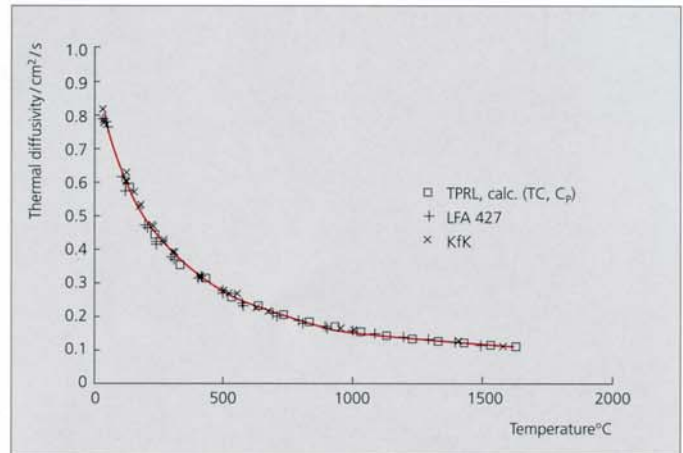


Perfect fit of the response curve (blue) due to the Cape-Lehmann model (red curve)

Comparative Measurements

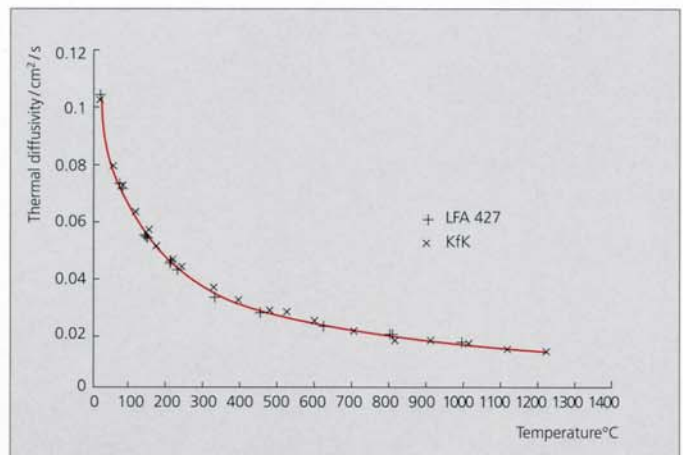
POCO graphite

This figure shows the results (LFA 427, KfK*) of thermal diffusivity measurements on POCO graphite compared to values calculated from measured thermal conductivity and specific heat data (TPRL**).



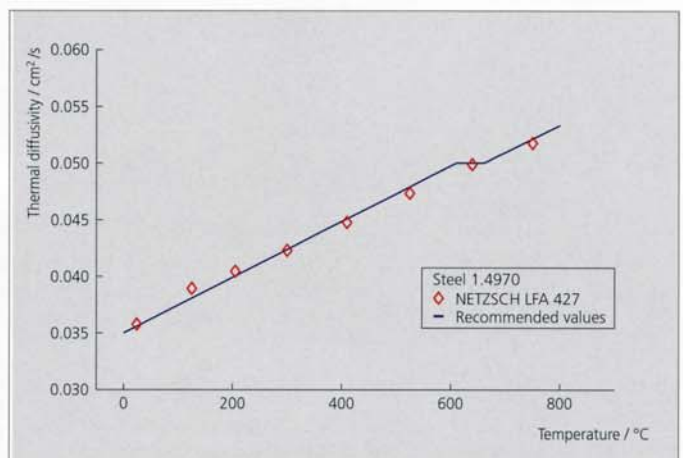
Bio-Al₂O₃

Test results (LFA 427, KfK*) are shown for a polycrystalline Bio-Al₂O₃ sample. Both faces were coated with a graphite emulsion.



1.4970 Steel

Shown here is the comparison of thermal diffusivity values measured with the LFA 427 and those recommended by the "Arbeitskreis Thermophysik" in Germany. The maximum deviation between the two sets of data occurs at 125°C and is only approximately 2.2%.



* Kernforschungszentrum Karlsruhe, IMF 1

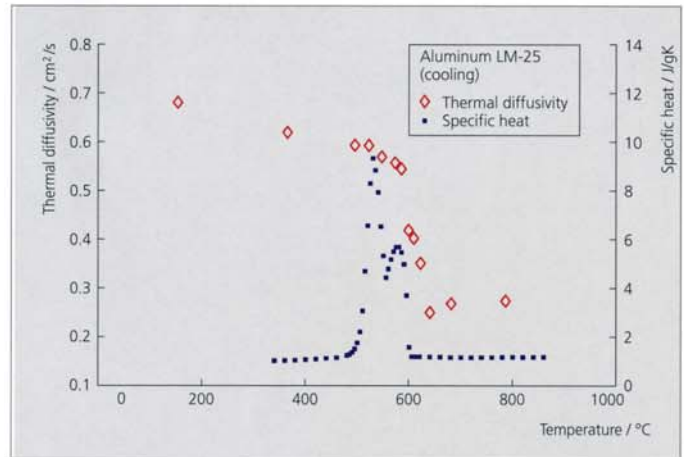
** Thermophysical Properties Research Laboratory, Purdue University, USA

Applications*

Aluminum Alloy

The thermophysical properties of metals and metal alloys in the solid, liquid and “mushy” (2-phase) regions are required for simulation of the casting process using numerical models. Shown here are both the thermal diffusivity and specific heat of LM-25 aluminum during cooling from the fully molten region. The solidification occurs between approximately 510 and 600°C. The large change in the thermal diffusivity across

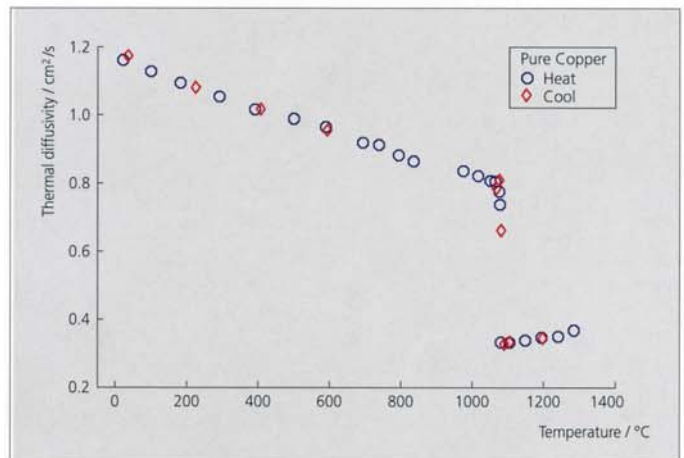
the “mushy” region is due, in part, to the change in the electronic component of the thermal conductivity. The specific heat data presented here deviate from known values by less than 3.0 and 2.0% in the solid and fully molten regions, respectively. The heat of fusion was determined to be 417 J/g and deviates from the known value by less than 2.0%. There were no data found for the thermal diffusivity in the solid or liquid region.



Pure Copper

The thermal diffusivity of pure copper was measured for both the heating and cooling cycles. The large change in the thermal diffusivity at approximately 1080°C is due primarily to the change in the electronic component of the thermal conductivity upon melting or solidification. The fact that there is almost no difference in the thermal diffusivity values between the heating and cooling cycles indicates

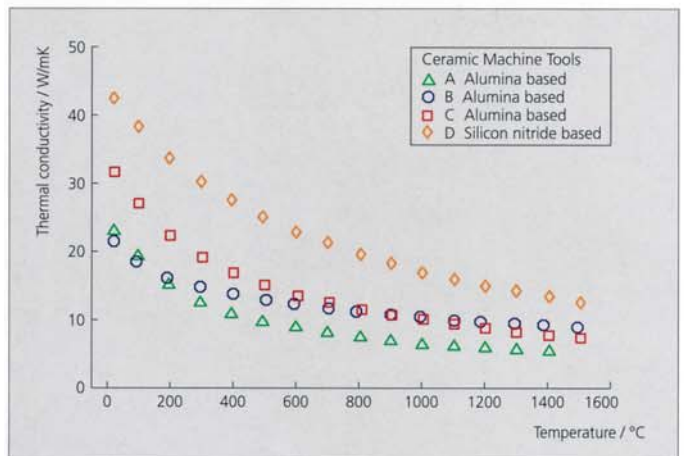
that no significant microstructural changes occurred. The measured values of the thermal diffusivity for both the solid and liquid regions deviated from those found in the literature by less than 2.5%. Note that the change in thermal diffusivity provides a good temperature calibration point for the LFA (melting point of pure copper = 1083°C).



Ceramic Machine Tools

Due to the increased machining speeds and better wear and chemical resistance, ceramics have replaced metals in many applications. However, since ceramics generally have lower thermal shock resistance, the temperature gradients which develop in the tools during use are of paramount importance. As a result, the thermal diffusivity (=> thermal conductivity) of these materials is a primary design consideration.

This figure shows the thermal conductivity of four ceramic machine tools. Ceramics A, B and C are all Al₂O₃-based, each with different secondary components, while sample D is Si₃N₄-based. The higher thermal conductivity of the Si₃N₄ allows it to be liquid cooled, while samples A and B must be used without liquid cooling. Sample C can be liquid cooled at lower temperatures.

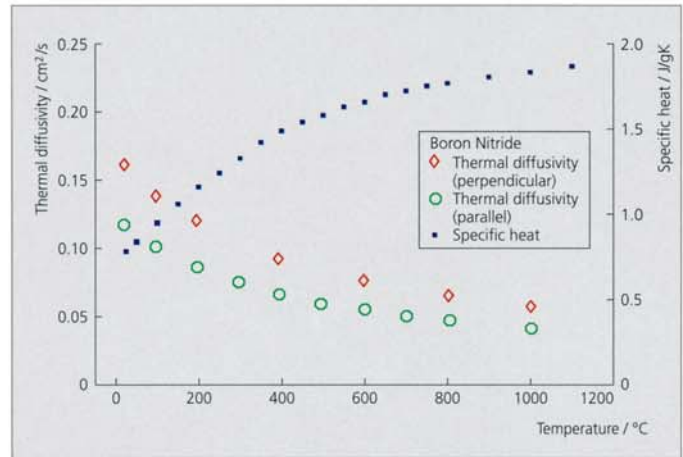


* The thermal diffusivity and specific heat for all application examples were measured with the LFA 427 and DSC 404, respectively. The thermal conductivity values were computed from the thermal diffusivity, specific heat and bulk density data.

Boron Nitride

Pure hexagonal boron nitride is a soft material (similar to graphite) and maintains its excellent insulating properties to temperatures above 2000°C. It is therefore used as a high-temperature insulating material. In addition, boron nitride has an excellent thermal shock resistance. This figure depicts the specific heat and thermal diffusivity of hot pressed boron nitride (bulk density $\approx 2.1 \text{ g/cm}^3$).

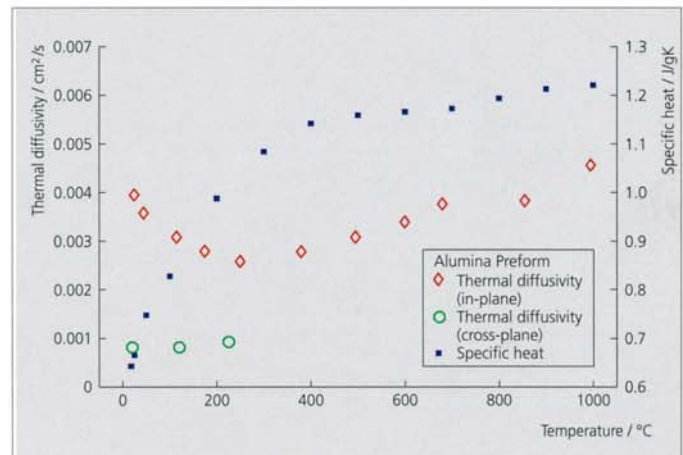
Because of its structure, the thermal diffusivity parallel to the direction of press is lower than that in the perpendicular direction. This, of course, is the expected behavior.



Squeeze Casting

Many metal matrix composites (MMC's) are manufactured by the squeeze casting process. Often a highly-porous preform such as Al_2O_3 is used as the reinforcing material. In this case, a molten metal is forced into the preform under pressure and allowed to solidify. Highly sophisticated numerical models are used to simulate and optimize this process. These models require, of course, a very accurate thermophysical property data base.

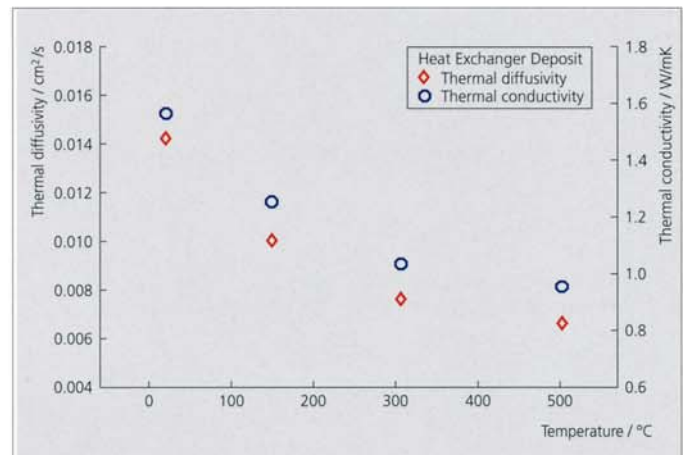
Presented here are the thermal diffusivity and specific heat of an Al_2O_3 preform. The thermal diffusivity data clearly show the anisotropic nature of the material. The diffusivity values for the cross-plane direction are much lower than those for the in-plane direction and display a different temperature dependence. No literature values for the thermal diffusivity or specific heat were found. The thermal diffusivity measurements were conducted under high vacuum.



Heat Exchanger Deposit

With time, heat-transfer surfaces in heat exchangers can become coated with various types of deposits. These deposits result in an additional resistance to heat flow, thereby lowering performance. This effect is usually referred to as fouling. In order to quantify the impact of fouling on heat exchanger efficiency, the thermal diffusivity

(\Rightarrow thermal conductivity) of the deposits must be determined. This figure depicts the measured temperature-dependent thermal diffusivity and calculated thermal conductivity of a heat exchanger deposit.



Technical Data

Temperature ranges:

-70 ... 400°C
25 ... 1300°C
25 ... 1550°C
25 ... 2000°C

Diffusivity range:

0.001 ... 10 cm²/s

Standard sample dimensions:

0.1 ... 6 mm thick
6.0 ... 12.7 mm diameter

Sample holder system:*

Al₂O₃ (max. 1700°C)
graphite (max. 2000°C)

Furnaces:

2000°C: graphite heating element with water-cooled housing
1550°C: silicon carbide heating element
1300°C: Kanthal heating element
400°C: Resistance heater with LN₂-cooling

Test atmospheres:

vacuum: 10⁻⁵ mbar (turbomolecular pump)
static/dynamic:
protective gas (Ar, He, etc.), oxidizing atmosphere

Laser

ND: GGG (neodymium: gallium-gadolinium-garnet)
power max.: 20 Joules/pulse
pulse width: variable
wave length: 1064 nm

IR detectors:

InSb (Indium-Antimonide)
MCT (Mercury Cadmium Telluride)
with liquid nitrogen cooling

Samples holders

standard 12.7 mm diameter
standard 10 mm diameter
standard 6 mm diameter
square samples: 10 x 10 mm
liquid materials
fibers
laminates
slags

System control and data acquisition:

Personal computer (IBM-compatible, Pentium 4)

Dimensions (W x H x D):

measuring unit:
60 cm x 170 cm x 70 cm
control cabinet:
60 cm x 120 cm x 70 cm

Power supply:

230 V, 50 Hz, max. 5 KVA

* Sample holders are also available for liquid metals, powders, etc.

Technical data subject to change