

LINSEIS

T H E R M A L A N A L Y S I S

THERMAL CONDUCTIVITY

LFA
PLH
TFA
THB
HFM
TF-LFA
TIM-Tester



Since 1957 LINSEIS Corporation has been delivering outstanding service, know how and leading innovative products in the field of thermal analysis and thermo physical properties.

Customer satisfaction, innovation, flexibility and high quality are what LINSEIS represents. Thanks to these fundamentals, our company enjoys an exceptional reputation among the leading scientific and industrial organizations. LINSEIS has been offering highly innovative benchmark products for many years.

The LINSEIS business unit of thermal analysis is involved in the complete range of thermo analytical equipment for R&D as well as quality control. We support applications in sectors such as polymers, chemical industry, inorganic building materials and environmental analytics. In addition, thermo physical properties of solids, liquids and melts can be analyzed.

LINSEIS provides technological leadership. We develop and manufacture thermo analytic and thermo physical testing equipment to the highest standards and precision. Due to our innovative drive and precision, we are a leading manufacturer of thermal Analysis equipment.

The development of thermo analytical testing machines requires significant research and a high degree of precision. LINSEIS Corp. invests in this research to the benefit of our customers.

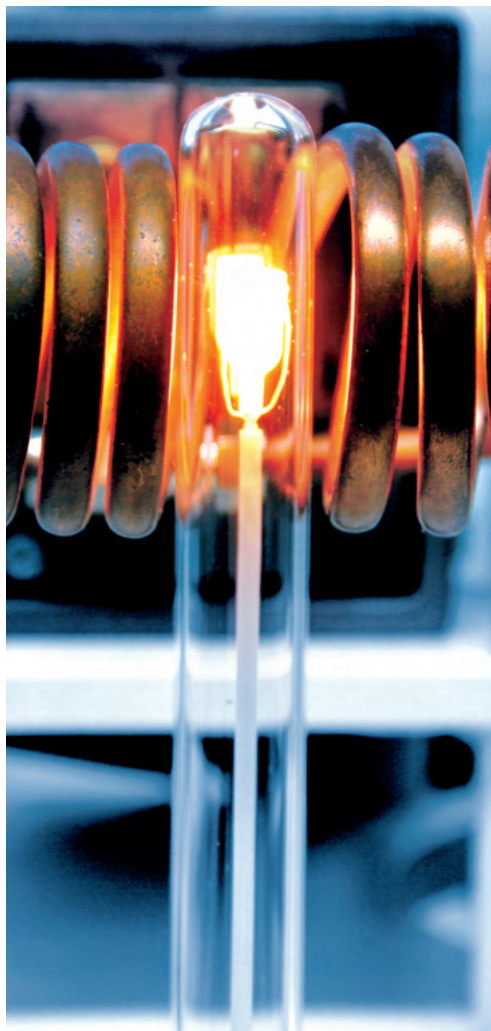


Claus Linseis
Managing Director



German engineering

The strive for the best due diligence and accountability is part of our DNA. Our history is affected by German engineering and strict quality control.

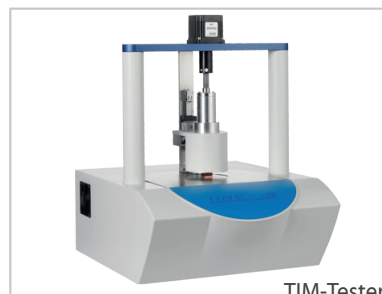
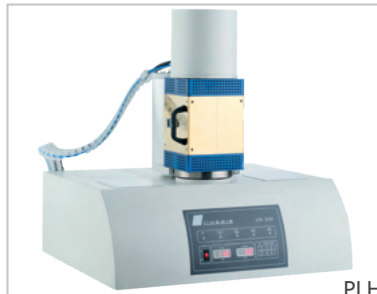
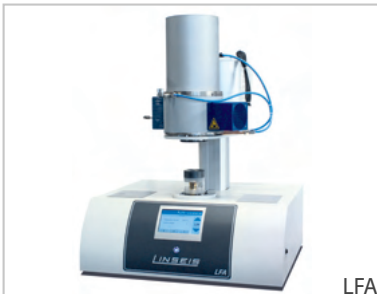


Innovation

We want to deliver the latest and best technology for our customers. LINSEIS continues to innovate and enhance our existing thermal analyzers. Our goal is constantly develop new technologies to enable continued discovery in Science.

PRODUCT OVERVIEW

Laser-Flash Analyzer, Thermal Interface Materials Tester, Transient Hot Bridge, Heat Flow Meter, Thin Film Laser Flash and Thin Film Analyser



MEASUREMENT DEVICES: AN OVERVIEW

The following table shall give an orientation concerning measurement devices and their capabilities. For more detailed information please contact our product and application specialists.

Devices	LFA	TIM-Tester	THB	HFM	TFA	TF-LFA
Info	Most universal tool	For thermal inter-face materials	For fast and easy measurement	For insulating materials	Thin films on LINSEIS chip	For nm to µm films
Measurement						
Thermal Conductivity						
Thermal Diffusivity						
Specific Heat Capacity						
Thermal Resistivity						
Defined Pressure on Sample						
Atmosphere						
Temperature range	-125°C to 2800°C	-20°C to +300°C	-150°C to +700°C	-40°C to +90°C	-170°C to +300°C	-100°C to +500°C
Price	\$\$-\$\$\$	\$\$	\$	\$\$	\$\$\$	\$\$\$
Sample Type						
Solid						
Liquid						
Powder						
Paste						
Pad						
Thin film						



Measurement is possible



Measurement is probably possible



Measurement is not possible

LFA - Laser Flash Analyzer

BULK

THIN FILM

Information about the thermophysical properties of materials and heat transfer optimization of final products is becoming more and more important for industrial applications. Over the past few decades, the flash method has developed into a commonly used technique for the measurement of the thermal diffusivity and thermal conductivity of various kinds of solids, powders, pastes and liquids. Application areas are electronic packaging, heat sinks, brackets, reactor cooling, heat exchangers, thermal in-

ulators and many more. Easy sample preparation, small required sample dimensions, fast measurement times and high accuracy are only a few of the advantages of this non-contact and non-destructive measurement technique.

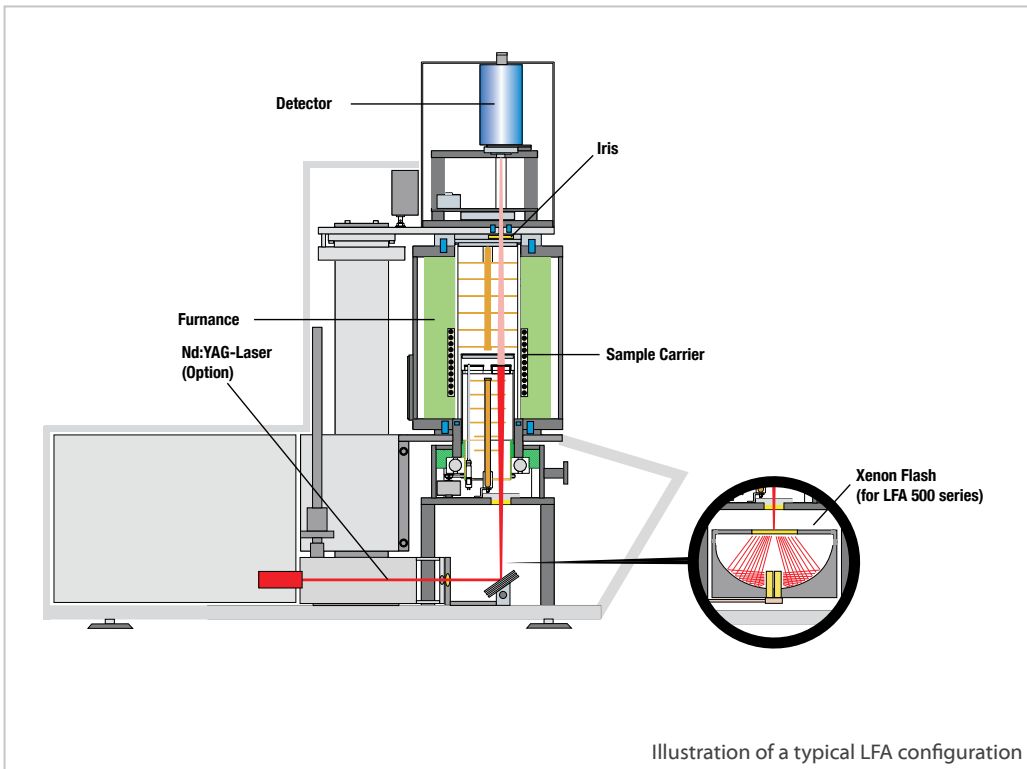
LINSEIS offers a variety of instruments to measure the thermal diffusivity/conductivity. The LFA 500/1000 Flash Analyzer series provides a cost effective solution for the temperature range from -125°C up to 2800°C .



SYSTEM DESIGN

The vertical arrangement with sensor on top, sample in the middle and heat pulse source (Laser/Xenon Lamp) on the bottom, ensures easy handling and best possible measurement results. The pulse energy and duration are adju-

stable in the range of 0.05 to 25 Joule/pulse and 0.05 to 5 ms. Due to this flexibility all kinds of demanding samples (even thin film or ultra-low thermal conducting samples) can be analyzed.



ABSOLUTE METHOD

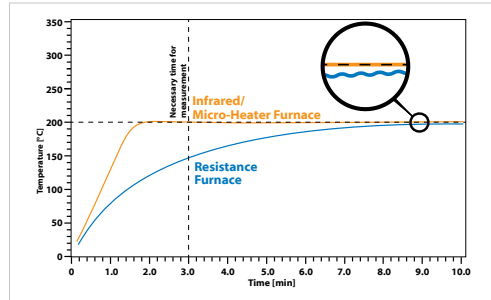
The used method is an absolute measurement technique (for thermal diffusivity), hence there is no need to calibrate the system. The LINSEIS

Flash Analyzers operate in agreement with national and international standards, such as ASTM E-1461, DIN 30905 and DIN EN 821.

HIGH SPEED FURNACE

The LFA unit is either equipped with a high speed infrared furnace (LFA 500 - 500/1000) or with an advanced microheater (LFA 500/1250). This technology enables unmatched heating and cooling speed, unmatched temperature control, homogeneity and precision.

Because time matters



Comparison: time to reach the temperature stability. A high speed IR-micro-heater furnace reaches the set temperature much faster and delivers a superior isothermal temperature stability

BULK

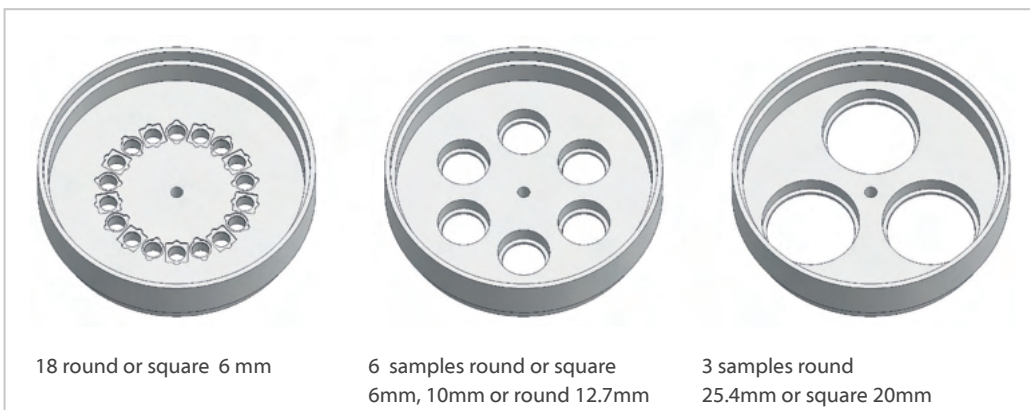
THIN FILM

DETECTORS

The system can be either equipped with an InSb or with a MCT detector, covering the complete temperature range from sub-ambient temperature up to 2800°C. Both are easily user exchan-

geable. An available automatic LN₂ refilling accessory with Dewar flask allows prolonged measurement cycles.

SAMPLE CARRIERS



SOFTWARE: COMBINED MODEL ACCORDING TO DUSZA

BULK

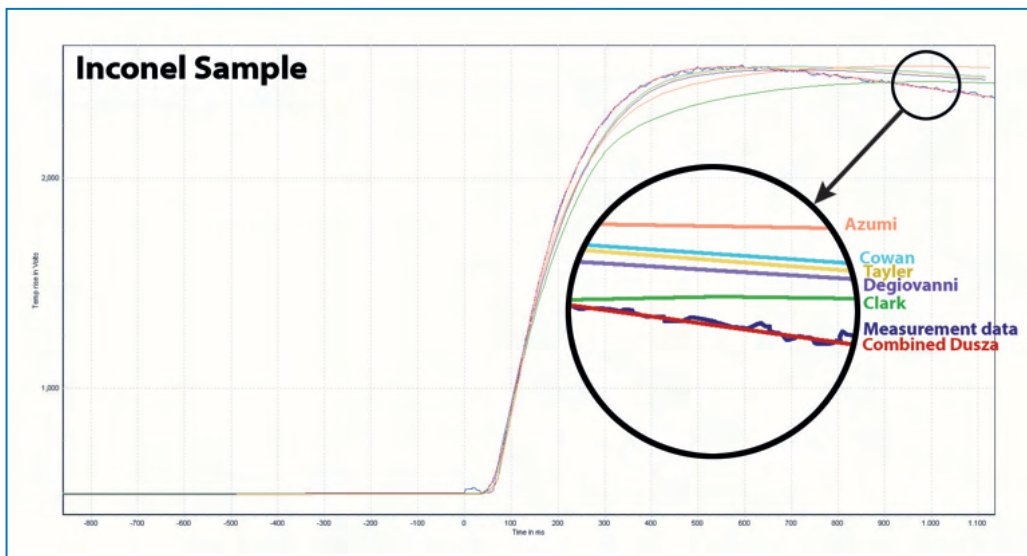
THIN FILM

Combining simultaneous heat loss and finite pulse-time corrections in a single evaluation model provides highest measurement accuracy.

One fits all

Easy controlling

No uncertainty



The plot illustrates a measurement on an Inconel sample. The raw data were evaluated using different common models. It can clearly be observed, that the combined model according to Dusza provides the best fit, resulting in the most accurate measurement result.

The combined model with non-linear parameter estimation has been proven for hundreds of samples. In all cases it worked reliably and its results gave the correct adiabatic, finite pulse-time and heat loss corrected values. The two main advantages of the method are that no

operator choice between the different models and corrections is necessary, and that it can be applied to any type of sample. The quality of the fit can be checked by plotting the model curve and also as a numeric value.

SPECIFICATIONS

BULK

THIN FILM

	LFA 500	LFA 1000
Temperature range	-100°C up to 500°C RT up to 500 / 1000 / 1250°C (Boost function: 1450°C)	-125/-100°C up to 500°C RT up to 1250 / 1600 / 2000 / 2400 / 2800°C
Heating rate	0.01 up to 300 K/min (depending on model)	0.01 up to 50 K/min
Thermal Diffusivity	0.01 up to 1000 mm ² /s	0.01 up to 1000 mm ² /s
Thermal Conductivity	0.1 up to 2000 W/(m·K)	0.1 up to 2000 W/(m·K)
Accuracy	Thermal diffusivity ± 2.4% Specific Heat ± 5%	Thermal diffusivity ± 2.4% Specific Heat ± 5%
Repeatability	Thermal diffusivity ± 1.9% Specific Heat ± 3%	Thermal diffusivity ± 1.9% Specific Heat ± 3%
Flash source	Light flash: up to 15 J/pulse variable (software controlled)	Laser Nd:YAG 28 J/pulse variable (software controlled)
Pulse width	0.05 up to 2 ms	0.05 up to 5 ms
IR-detector	InSb: RT up to 1450°C MCT: -100°C up to 500°C	InSb: RT up to 2800°C MCT: -125°C up to 500°C
Atmosphere	inert, oxidizing, reducing, vacuum	inert, oxidizing, reducing, vacuum
Vacuum	up to 10 ⁻⁵ mbar	up to 10 ⁻⁵ mbar
Data acquisition	10 MHz	10 MHz
Sample holders	round or square - solid samples, powders, pastes, li- quids, laminates - special holder for measurement under mecha- nical pressure	round or square - solid samples, powders, pastes, li- quids, laminates - special holder for measurement under mecha- nical pressure
Sample numbers	sample robot up to 3, 6 or 18 samples (depends on model)	up to 3, 6 or 18 samples

PLH - Periodic Laser Heating

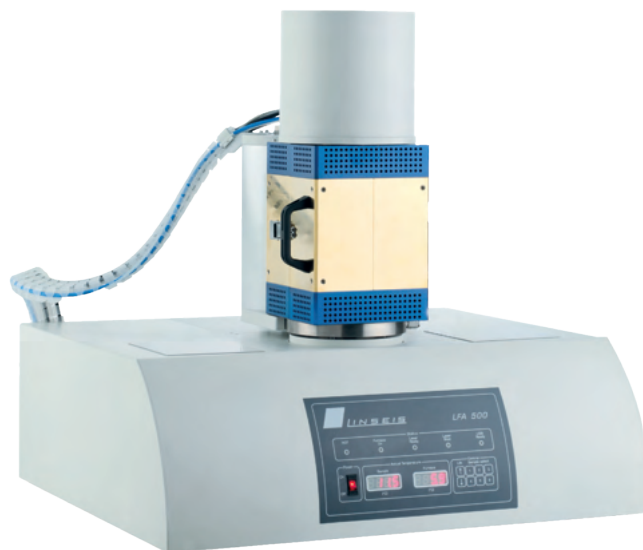
The characterization of micrometer materials is a critical issue today due to ongoing R&D for new technologies, such as battery and hydrogen applications, as well as miniaturization efforts.

Due to the large surface to volume ratio, these types of materials need to be studied separately from bulk materials, but sample preparation and measurements can be very challenging.

In addition to our well-established laser flash technique, the PLH setup allows us to extend the measurement range of our non-destructive optical instruments in terms of thickness and thermal transport properties.

The PLH has been developed and optimized to characterize samples with high accuracy over a measurement range of sample thickness from 10 μm to 500 μm and a thermal diffusivity range of 0.01 - 2000 mm^2/s .

The system can handle a wide range of materials. It is possible to measure samples with semi-conducting behavior as well as metals, ceramics or polymers. Typical applications include free-standing films and membranes for the battery and hydrogen industries.

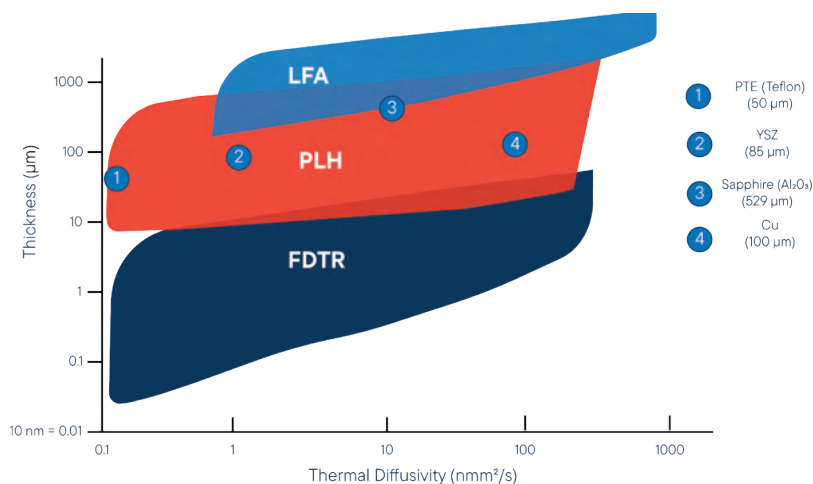


SPECIFICATIONS

	PLH
Temperature range	RT up to 300°C
Heating range	0.01 up to 20 °C/min
Samples dimensions	Ø 3, 6, 10, 12.7 or 25.4 mm square 5x5, 10x10 or 20x20 mm
Sample thickness	10 - 500 µm
Sample robot	robot with 3 or 6 samples
Laser source	CW diode laser up to 5 W wavelength: 450 nm
Thermal diffusivity	0.01 to 2000 mm ² /s (thickness depended)
Accuracy	±5%
Repeatability	±5%
Footprint	550 x 600 x 680 mm 21,6 X 23,6 X 26,7 inch

ASTM Normen LFA: ASTM E-1461, DIN 30905 and DIN EN 821

ASTM Normen PLH: JIS R 7240:2018 & ISO: 20007:2017



TIM-TESTER

BULK

THIN FILM

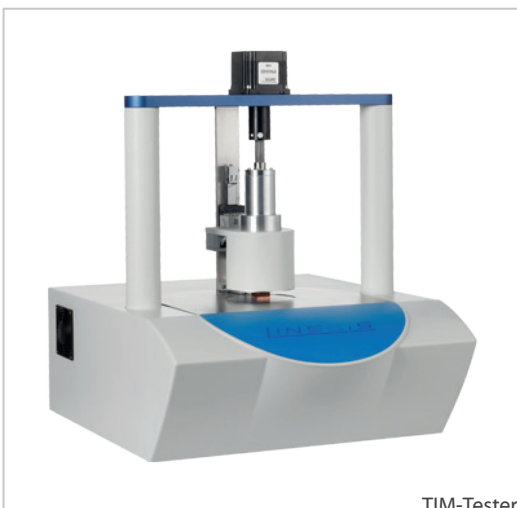
Waste heat management and thermal runaway protection in batteries and electronic packaging is becoming more and more important as power densities of these devices increase. Thermal management of these complex systems is not trivial and requires a fundamental understanding of how components and interface materials work together to shed heat.

Our LINSEIS Thermal Interface Material Tester (TIM-Tester) is the perfect solution for thermal management optimization of these complex systems.

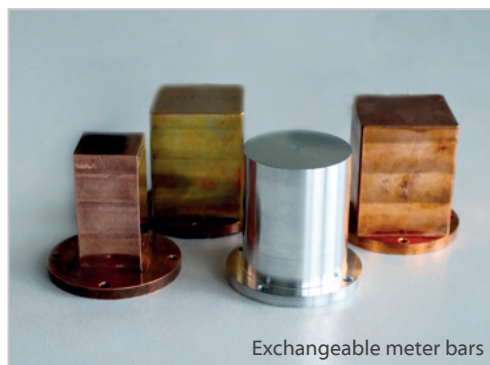
The TIM-Tester measures the thermal impedance of sample materials and identifies an apparent thermal conductivity for a wide range of materials from liquid compounds and pastes to hard solid materials. **The approach is consistent with the ASTM D5470 standard.**

Thermal interface materials such as thermal fluids, thermal pastes or greases, phase change materials (PCM), solders or resilient thermal conductors are tested automatically by applying a pressure of up to 10 MPa (for \varnothing 25mm sample) and temperature of up to 300°C at the hot side.

The software interface allows the instrument to be operated automatically over a wide temperature and pressure range, while all test parameters are recorded in real time. Different instrument configuration for square or round shaped samples of different size can be analysed under variable load in order to optimize materials for a specific application.



TIM-Tester



Exchangeable meter bars

SPECIFICATIONS

BULK

THIN FILM

	TIM-Tester
Sample temperature range (max)	-30°C to 300°C*
Standard sample size	Round: \varnothing 20 mm, 25 mm, 40 mm Rectangular: 20 mm x 20 mm, 25 mm x 25 mm, 40 x 40 mm Other sizes on request
Sample thickness	0.01 mm to 8 mm (up to 20 mm)
Sample measurement range	0.1 – 50 W/mK
Sample resistance range	0.01 – 8.0 K/W
Contact pressure range	0 bis 16 MPa (je nach Probengröße und -form) Von rund \varnothing 20mm (bis zu 16 MPa) bis \varnothing 40 mm (bis zu 4 MPa) und rechteckig 20mm x 20mm (bis zu 8 MPa)
Force options	1000 N, 2000 N, 5000 N (also possible: 1 kN, 2 kN, 5 kN)
Meter bar material	Aluminium, Copper, Brass (others on request)
Software Plugins	Thickness modulation Temperature cycling Quality management tool
Cooling options	Standard water cooling unit, intracooler 600 (-20°C cold side)**, intracooler 1000 (-30°C cold side)**
Power supply	110/115/220/230 VAC 50/60 Hz

* Under optimum conditions

** Lowest cold side meter bar temperature under optimum conditions

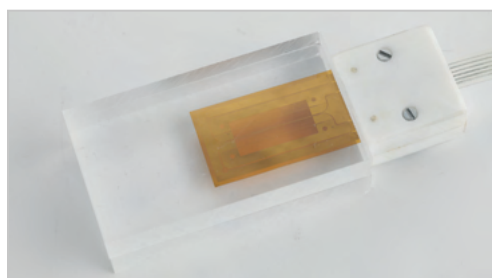
THB – TRANSIENT HOT BRIDGE

Instrument for rapid measurement of thermal conductivity, thermal diffusivity and specific heat

A flexible sensor is sandwiched between two flat surfaces of the specimens to assure a good thermal contact without air inclusions. Either the delivered sample holder or a weight can be used in order to optimize the contact resistance. The shapes of the faces, which are not in contact with the sensor, are of no importance, which helps to reduce the sample preparation to a minimum. There are no limitations regarding the maximum sample size, where else the minimum thickness depends on the samples thermal diffusivity. The measurement and evaluation are completely software controlled, run automatically and can be post-processed if needed. Measurements take only some seconds up to a few minutes. The sensors are automatically identified by the software. Multiple measurements with automatic calculation of the mean

values are possible as well as the storage of results.

Measurements can be done either at room temperature (no further equipment required), elevated or sub-ambient temperatures. The setup, including the sensor, can be placed in a normal lab furnace or climatic chamber, which are often available in laboratories. LINSEIS also offers specially adapted furnaces covering temperatures from -150°C up to 700°C .



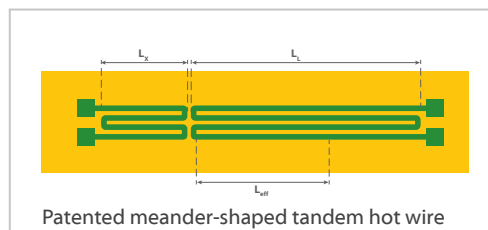
THE MEASUREMENT SET-UP

Advantages

- Short measurement times (seconds to few minutes)
- High accuracy due to patented sensor design
- Easy set-up and sample preparation
- Non-destructive measurement
- Absolute method - no calibration required
- Suitable for solids, liquids, powders, pastes etc.
- Temperature range -150°C to 700 °C
- Measurements at different atmospheres, vacuum and pressures up to 150 bar
- Broad thermal conductivity range from 0.005 to 1800 W/m·K
- Modular design

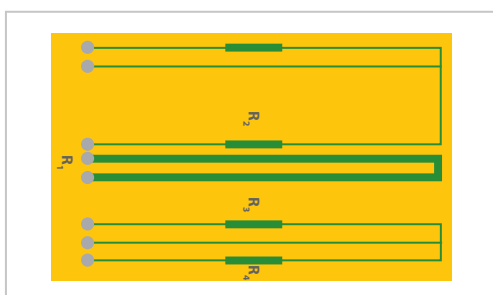
Transient Hot Bridge Method

The THB measurement method, initially developed by the National Metrology Institute of Germany (PTB), is an optimized hot wire technique to measure all relevant thermal transport properties (thermal conductivity, thermal diffusivity and volumetric specific heat) with the highest possible accuracy.

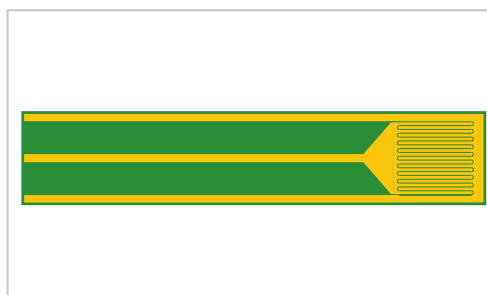


For the THB-Advance and THB-Ultimate additional hot wire measurement techniques are available, based on innovative and patented sensors:

The Quasi-Steady-State (QSS) sensors have been developed for the measurement of high thermal conductivities. It combines the advantages of steady-state and transient measurement techniques and enables measurements in the range up to 1800 W/m·K



The LINSEIS Hot Point Sensors (HPS) work according to the transient plane method. They are suitable to measure small samples with dimensions down to 3 x 3 mm². The thermal conductivity range of 0.01 to 30 W/m·K is covered by the Hot Point Sensor.



SPECIFICATIONS

All sensor types are available as Kapton-foil-sensors and resist to temperatures from -150°C up to 200°C. Ceramic sensors are available covering

a temperature range up to +700°C (THB Basic and THB Advance).

	THB Basic	THB Advance	THB Ultimate
THB Sensors	✓	✓	✓
QSS Sensors	✗	✓	✓
Hot Point Sensors	✗	✓	✓

Measuring ranges	THB Basic	THB Advance	THB Ultimate
Thermal Conductivity	0.01 to 5 W/(m·K)	0.005 to 500 W/(m·K)	0.005 to 1800 W/(m·K)
Thermal Diffusivity	0.05 to 50 mm ² /s	0.05 to 300 mm ² /s	0.05 to 1200 mm ² /s
Special thermal capacity	100 to 5000 kJ/(m ³ ·K)	100 to 5000 kJ/(m ³ ·K)	100 to 5000 kJ/(m ³ ·K)
Measurement uncertainties			
Thermal Conductivity	better than 1%	better than 1%	better than 1%
Thermal Diffusivity	better than 4%	better than 4%	better than 4%
Specific Heat	better than 4%	better than 4%	better than 4%
Duration of the measurement	typically < 1 min	typically < 1 min	typically < 1 min
Service temperature			
Sensor	-150°C to 200°C	-150°C to 700°C	-150°C to 700°C
Sensor type	Kapton and Ceramic	Kapton and Ceramic	Kapton and Ceramic
Sample size			
Smallest sample	10 x 20 x 3 mm	3 x 3 x 2 mm	3 x 3 x 2 mm
Sample consistency	solid, liquid, gel	solid, liquid, gel	solid, liquid, gel

HFM - HEAT FLOW METER

The Heat Flow Meter provides a rapid and easy to use method to determine the thermal conductivity properties of low thermal conductivity materials (e.g. like insulating materials) with a high level of accuracy. The instrument is designed for ASTM C518, JIS A1412, ISO 8301 and DIN 12667. The principle of measurement is to po-

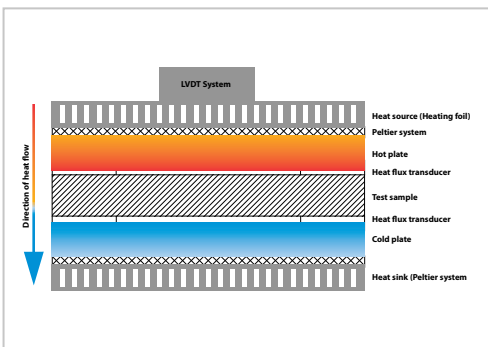
sition a sample between a hot and a cold plate, and to measure the heat flow.

Service and maintenance

The robust system design and the unique "zero maintenance" Peltier heating and cooling cycle ensures a minimum of cost.

Test cycles

The double heat flux sensor configuration ensures shortest possible measurement cycles. A typical measurement can take as little as 15 minutes until the temperature stabilizes. Two heat flux sensors then measure the heat flow from which the thermal resistance and thermal conductivity are calculated.



TF-LFA - FDTR

Frequency Domain Thermoreflectance

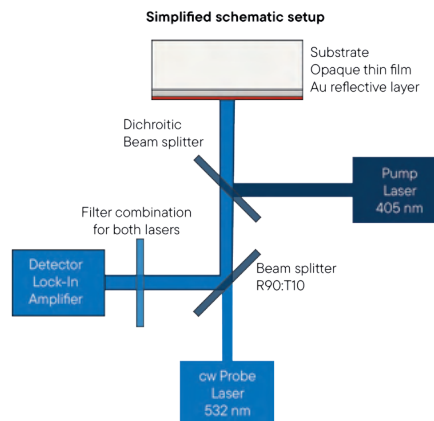
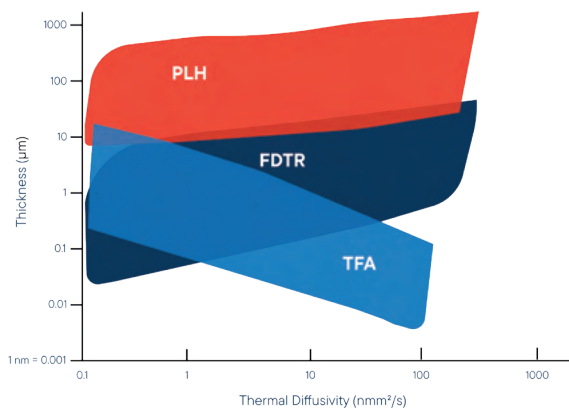
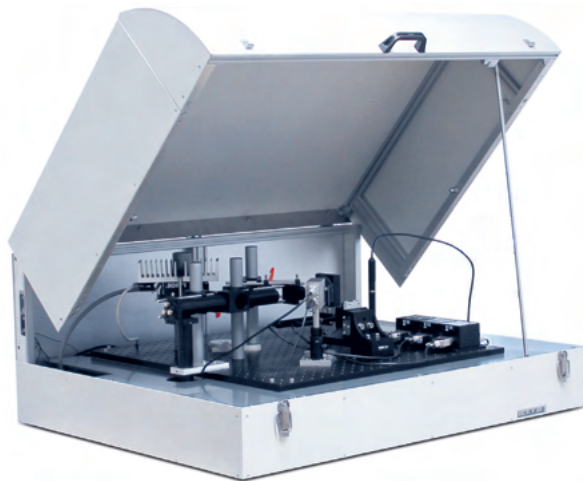
NEW

THIN FILM

Thermophysical properties of thin films are becoming more and more important in industries such as phase-change optical disk media, thermo-electric materials, light emitting diodes (LEDs), phase change memories, flat panel displays, and semiconductors. In all these applications thin films are deposited on substrates in order to give a device a particular function. Since the physical properties of these films significantly differ from bulk

material, data of thin films are required for accurate thermal management predictions.

Therefore we developed the LINSEIS TF-LFA (Thin-Film-Laser-Frequency-Analyser), allowing to measure the thermo-physical properties thermal conductivity, thermal diffusivity, thermal effusivity, the volumetric heat capacity and the thermal boundary conductance of thin films in the thickness range of 80 nm to 20 μm .



TFA - THIN FILM ANALYZER

The LINSEIS Thin Film Analyzer TFA is the perfect solution to characterize a broad range of thin film samples in a very comfortable and quick way. It is an easy to use, single stand alone system and delivers high quality results using an optimized measurement design as well as the proven LINSEIS firm- and software package.

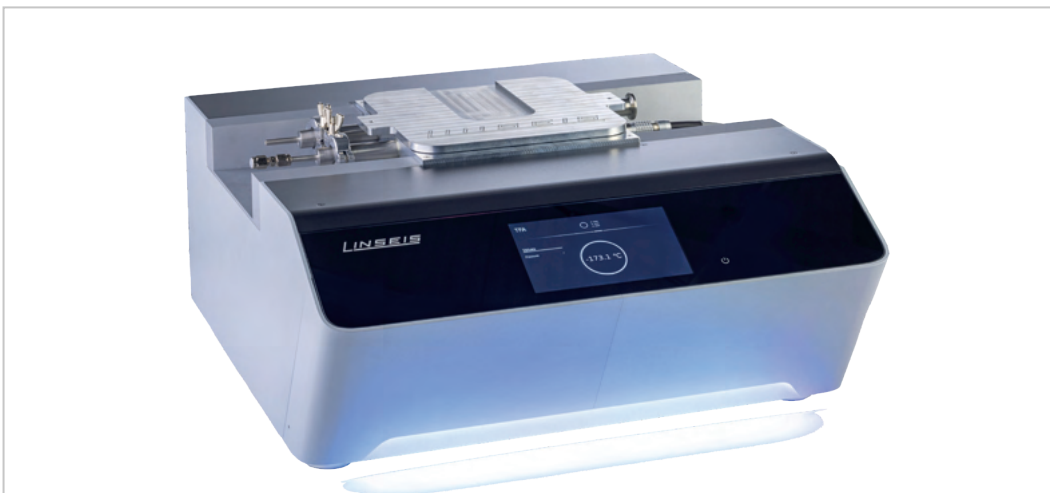
Motivation

Due to new research efforts in the field of semi-conducting materials, with a focus on size effects, there is a growing need for measurement setups dedicated to samples with small geometrical dimensions like thin films and nanowires, with considerably different physical properties than bulk material. The characterization of these samples is important in order to learn more about their structure and conduction mechanism and also important for technical applications.

Measurement Setup

The LINSEIS TFA is a chip-based platform to simultaneously measure the in-plane electrical and thermal conductivity, the Seebeck coefficient as well as the Hall constant of a thin film sample in the temperature range from -170°C up to 280°C and in a magnetic field of up to 1 T. Due to the design of the setup, time consuming preparation steps can be omitted and a nearly simultaneous measurement of the sample properties is achieved. Typical errors caused by different sample compositions, varying sample geometries and different heat profiles are avoided with this measurement method.

The system can handle a broad range of different materials. It is possible to measure samples with semiconducting behaviour as well as metals, ceramics or organic materials. Therefore many different deposition methods like PVD, CVD, spin coating or drop casting can be used.



TFA OPTIONS

The following packaging options are available for the LINSEIS Thin Film Analyzer (TFA):

1. Basic device

Consists of measurement chamber, vacuum pump, basic sample holder with included heater, system integrated lock-in amplifier for the 3ω -method, PC and LINSEIS software package including measurement and evaluation software. The design is optimized to measure following physical properties:

- λ - thermal conductivity
- c_p - specific heat

2. Thermoelectric package

Consisting of extended measurement electronics (DC) and evaluation software for thermoelectric experiments. The design is optimized for measuring the following parameters:

- σ - electrical conductivity / electrical resistivity
- S - Seebeck coefficient

3. Magnetic package

The design is optimized for measuring the following parameters:

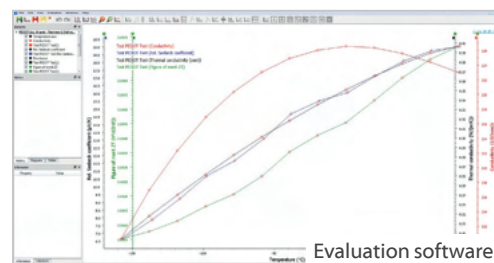
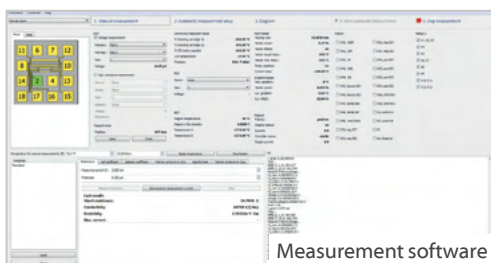
- A_H - Hall constant
- μ - Mobility
- n - charge carrier concentration

4. Low temperature option for controlled cooling down to 100 K

- TFA/KREG controlled cooling unit
- TFA/KRYO Dewar 25l

Software

The TFA software package consists of two parts. A measurement software which displays the actual values and which allows to define a measurement routine and the direct control of the setup. And an additional evaluation software for the post processing of the measured raw data.



MEASURING PRINCIPLES

Pre-structured measuring chips

The thin film to be analyzed has to be deposited on a pre-structured disposable chip available from LINSEIS. All necessary sensing arrangements are integrated in this chip. The chip is combining the 3ω measurement technique for the thermal conductivity measurement with a 4-point Van-der-Pauw setup for the determination of the electrical transport properties. The Seebeck coefficient can be measured using additional resistance thermometers located near the sample. For an easy sample preparation either a strip-off foil mask or a metallic shadow mask can be used. This configuration allows for a nearly simultaneous characterization of a sample which has been prepared by either PVD (e.g. thermal evaporation, sputtering, MBE), CVD (e.g. ALD), spin coating, drop casting or ink-jet printing in one step.

Van-der-Pauw measurement

To determine the electrical conductivity (σ) and Hall constant (A_H) of the sample, the Van-der-Pauw method is used. After depositing the sample on the chip, it is already connected to four electrodes A, B, C & D at their edge. For the

measurement, a current is applied between two of the contacts and the corresponding voltage between the remaining two is measured. By clockwise changing of the contacts and repeating of the procedure, the resistivity of the sample can be calculated using the Van-der-Pauw equation.

$$\exp\left(-\frac{\pi d}{\rho} \cdot R_{AB,CD}\right) + \exp\left(-\frac{\pi d}{\rho} \cdot R_{BC,DA}\right) = 1$$

By applying a magnetic field and measuring the corresponding change of the diagonal Van-der-Pauw resistance, the Hall constant of the sample can be calculated.

$$A_H = \frac{d}{B} \cdot \Delta R_{AC,BD}$$

For the determination of the Seebeck coefficient, an additional thermometer and heater is placed on the chip near the sample. This configuration allows for the measurement of the thermovoltage at different temperature gradients which can be used in order to calculate the Seebeck coefficient $S = -V_{th}/\Delta T$.

$$S = -V_{th} / \Delta T$$



SPECIFICATIONS

	TFA
Temperature range	RT up to 280°C -160°C up to 280°C
Sample thickness	from only a 5 nm to 25 µm (range depends on sample)
Measurement principle	chip based (pre-structured measurement chips, 24 pcs. per box)
Desposition techniques	include: PVD (sputtering, evaporation), ALD, spin coating, ink-jet printing and more
Measured parameters	Thermal conductivity (3ω) Specific heat
Optional	Seebeck coefficient Electrical resistivity / conductivity Hall constant / Mobility / Charge carrier concentration Permanent magnet 0.5 T or Electromagnet up to 1 T
Vacuum	up to 10 ⁻⁵ mbar
Electronics	integrated
Interface	USB
Measurement range	
Thermal Conductivity	0.05 up to 200 W/m·K
Electrical Resistivity	0.05 up to 1 · 10 ⁶ S/cm
Seebeck Coefficient	1 up to 2500 µV/K
Hall mobility	1 up to 10 ⁷ (cm ² /Volt sec)
Charge carrier concentration	10 ⁷ up to 10 ²¹ (1/cm ³)
Repeatability & accuracy	
Thermal conductivity	± 10% (for most materials)
Electrical resistivity	± 6% (for most materials)
Seebeck coefficient	± 7% (for most materials)
Hall constant	± 9 % for most materials

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