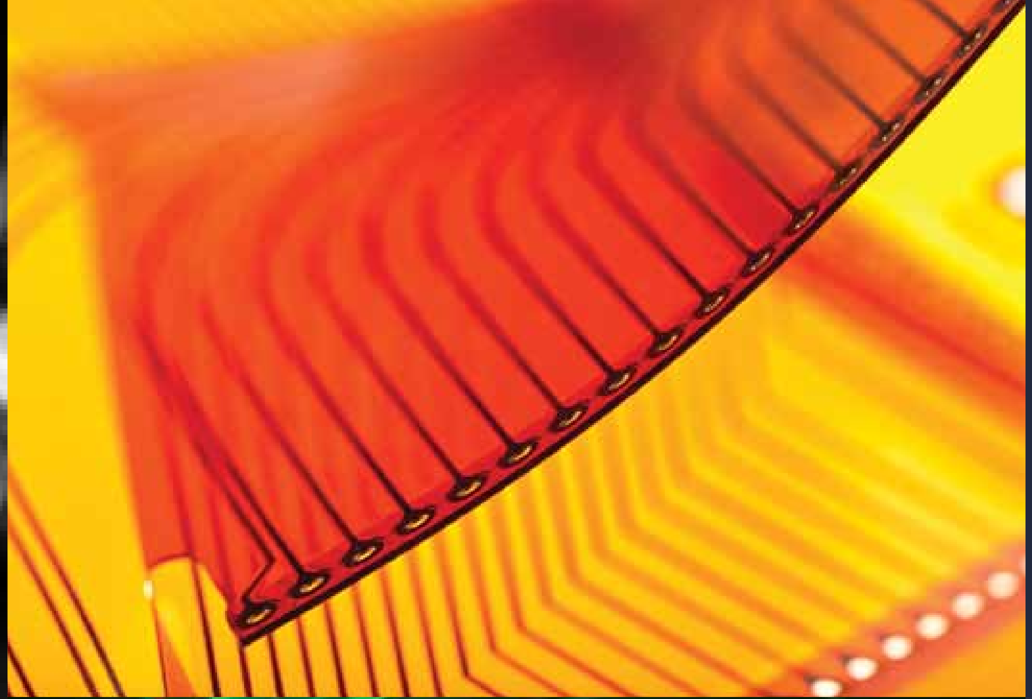
TA Instruments

THERMOPHYSICAL PROPERTIES



Introduction

Thermophysical properties are those material properties that vary with temperature while maintaining a constant chemical identity. Thermal diffusivity, thermal conductivity and specific heat capacity are among the most practical of these properties, as they relate directly to a material's ability to store and transfer heat.

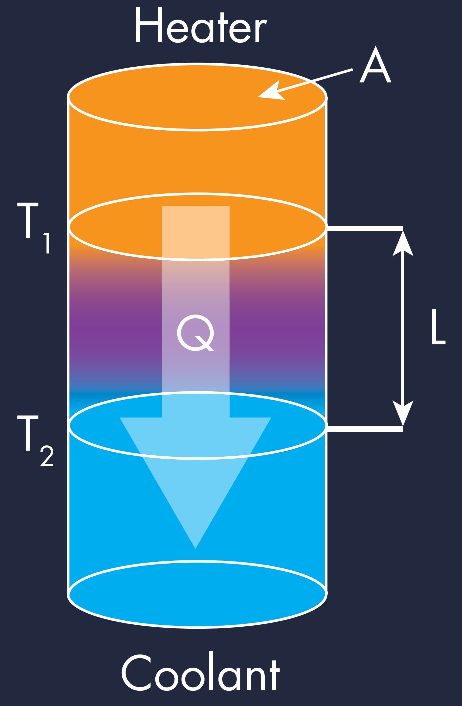
The precise and accurate measurement of these properties is critical for any process or material, which experiences a large or fast temperature gradient, or for which the tolerance for temperature change is exacting. Accurate thermophysical property values are essential for modeling and managing heat, whether the component of interest is called on to insulate, conduct, or simply tolerate temperature changes. Information about these properties are routinely used in heat transfer models of all complexities. Thermophysical property measurements also reflect important information about material composition, purity and structure, as well as secondary performance characteristics such as tolerance to thermal shock.

Thermal Conductivity **Introduction**

Heat transfer by conduction is governed by Fourier's Law, which defines the thermal conductivity, λ:

$$\lambda = \frac{Q/A}{\Delta T/L}$$

The heat flow, Q, through a cross-sectional area, A, arises from a temperature drop, ΔT, over a length, L. The steady-state measurement of thermal conductivity relies on accurate measurement of the heat flow and temperature gradient.

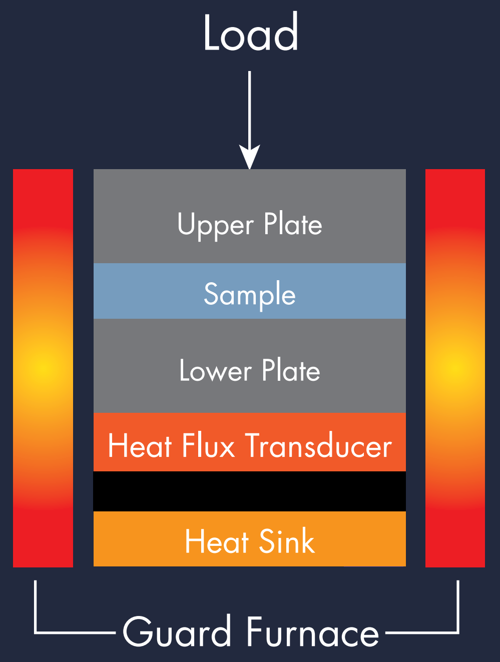


The TA Instruments DTC-25 and DTC-300 Thermal Conductivity Meters measure thermal conductivity according to the ASTM E1530 guarded heat flow meter method. In this technique, a sample of the material to be tested is held under a compressive load between two surfaces, each controlled at a different temperature. The lower surface is part of a calibrated heat flux transducer. As heat is transferred from the upper surface through the sample to the lower surface, an axial temperature gradient is established in the stack. By measuring the temperature difference across the sample along with the output from the heat flux transducer, thermal conductivity of the sample can be determined when the thickness is known.

The DTC-25 operates at room temperature, so lateral heat losses are negligible. The DTC-300 operates at higher temperatures where lateral heat losses to the environment would introduce measurement error. This error is eliminated through use of a guard furnace, which is set to the sample temperature; this minimizes lateral heat losses and ensures the highest measurement accuracy.

Positive thermal contact is required and is ensured by applying a reproducible, pneumatic load to the test stack. For rough samples, thermal interface pastes may also be used. When working with materials that tend to creep under load, stops may be used to define the gap at a specified value. The DTC-25 and DTC-300 are commonly employed for measurements of solids such as neat and filled polymers. Measurement systems are also available for use with pastes and liquids, making the Discovery Thermal Conductivity instrument an extremely versatile system.

Test Section Schematic



DTC-25

The DTC-25 Thermal Conductivity Meter is a single temperature test instrument used for quick determination of thermal conductivity of solid materials using the guarded heat flow method. Because of its simple operation, small sample size, and short cycle time, the DTC-25 is ideally suited for quality control and screening of materials. Metals, ceramics, polymers, composites, glass and rubber can all be tested accurately. Thin samples like paper products and plastic films can also be tested.

The DTC-25 is completely self-contained and requires no additional instrumentation for the measurement. The instrument is factory-calibrated using specimens of known thermal resistance spanning the range of the instrument. Calibration reference sets are also available. An optional chiller providing coolant at a fixed temperature is recommended for optimal performance. The DTC-25 is a simple, fast and accurate laboratory instrument.

DTC-25 SPECIFICATIONS

Method	Guarded Heat Flow Meter
Standard Test Method	ASTM E1530
Sample Compatibility	solids, pastes, liquids, thin films
Sample Size	
Thickness	Maximum 32 mm depending on thermal resistance. Thin films down to 0.1 mm, with optional software
Diameter	50 mm
Temperature Range	Near ambient
Thermal Conductivity Range	0.1 to 20 W/m·K
Thermal Resistance Range	0.0004 to 0.012 m^2 K/W
Accuracy	±3%
Reproducibility	±2%

DTC-300

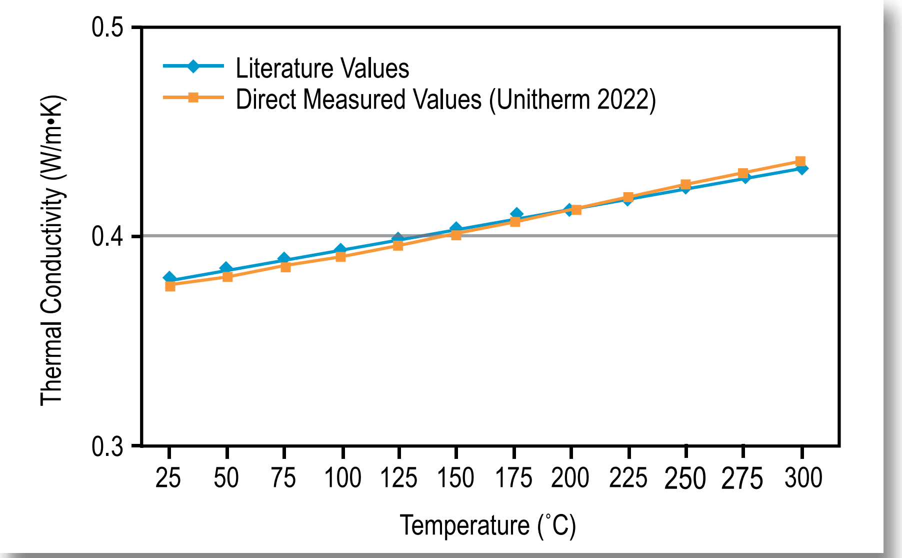
The DTC-300 is a guarded heat flow meter used to measure thermal conductivity of a variety of materials, including polymers, ceramics, composites, glasses, rubbers, some metals, and other materials of low to medium thermal conductivity. Only a relatively small test sample is required. Non-solids, such as pastes or liquids, can be tested using special containers. Thin films can also be tested accurately using a multi-layer technique. The tests are performed in accordance with the ASTM E1530 standard.

A water-cooled heat sink allows operation with a lowest sample temperature of about 50°C. To fully utilize the range of the instrument, an optional refrigerated circulator can be used to provide a heat sink temperature to -40°C. The instrument is provided with one of three operating range modules. Each module covers a different thermal resistance region. The various modules are easily interchangeable.

DTC-300 SPECIFICATIONS

Method	Guarded Heat Flow Meter
Standard Test Method	ASTM E1530
Sample Compatibility	solids, pastes, liquids, thin films
Sample Size	
Thickness	25 mm maximum Thin films down to 0.1 mm with optional software
Diameter	50 mm diameter
Temperature Range	-20°C to 300°C
Thermal Conductivity Range	0.1 to 40 W/m·K
Thermal Resistance Range	[1] 0.0005 – 0.010 m^2 K/W [2] 0.002 – 0.020 m^2 K/W [3] 0.01 – 0.05 m^2 K/W
Accuracy	±3%
Reproducibility	±1-2%

Applications



Vespel® Thermal Conductivity

The data contained in the figure and table demonstrate the impressive accuracy and precision of the DTC-300 Thermal Conductivity Meter on the standard material, Vespel. As shown in the table, the measured error is less than 1% across the entire temperature range from ambient to 300°C.

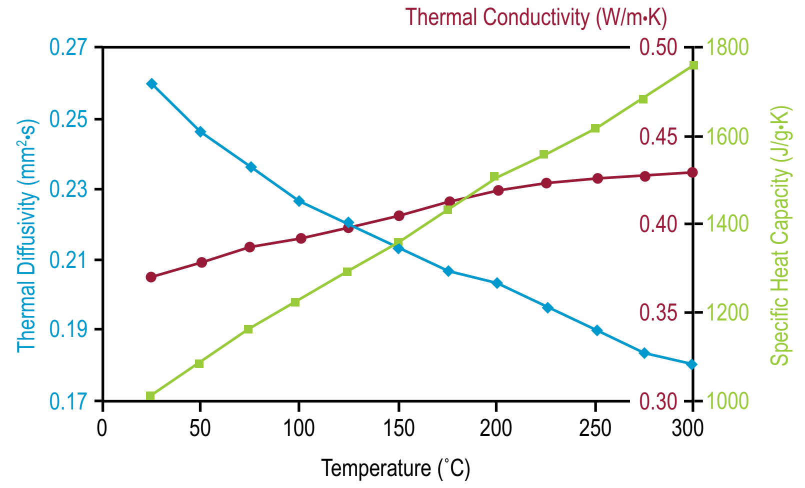
Thermal Conductivity (W/m·K)

Temperature (˚C)	Direct Measurement	Literature Values	Error (%)
25	0.377	0.379	0.53
50	0.381	0.384	0.78
75	0.386	0.389	0.77
100	0.391	0.394	0.76
125	0.396	0.399	0.75
150	0.402	0.404	0.50
175	0.407	0.409	0.49
200	0.413	0.414	0.24
225	0.419	0.419	0.00
250	0.425	0.424	0.24
275	0.430	0.429	0.23
300	0.436	0.434	0.46

Vespel Thermal Diffusivity

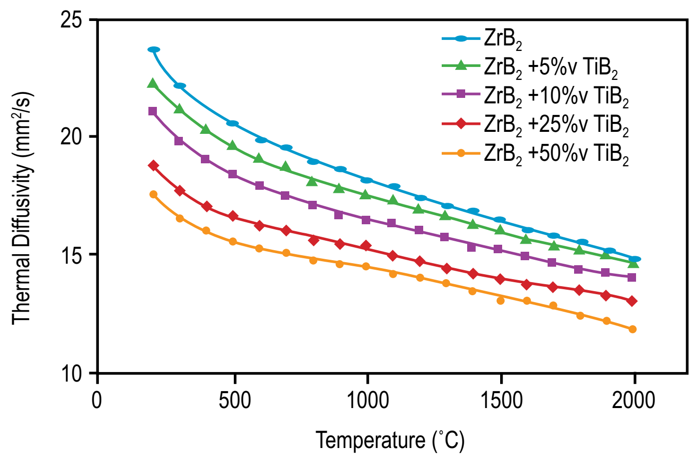
Vespel is a polyimide which is one of the commonly used thermal conductivity reference materials, due to its consistent thermophysical properties. There is, however, very little data available describing its thermal diffusivity and specific heat capacity.

This figure presents data for thermal diffusivity and specific heat capacity obtained using the flash method, with the latter also determined using a differential scanning calorimeter. From these data (and the equation found on Page 4), thermal conductivity can be determined. The calculated thermal conductivity is in good agreement with the values directly measured from the Guarded Heat Flow technique (shown on the previous page).



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 3000°C. ZrB_2 is also remarkable for its high strength and hardness, good chemical stability and high thermal and electrical conductivities, making 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 transport properties at temperature is critical to managing this heat. As seen in the figure, increasing the solid solution content of TiB_2 in ZrB_2 decreases thermal diffusivity over the entire use temperature range, which is readily elucidated by the DLF-2800.



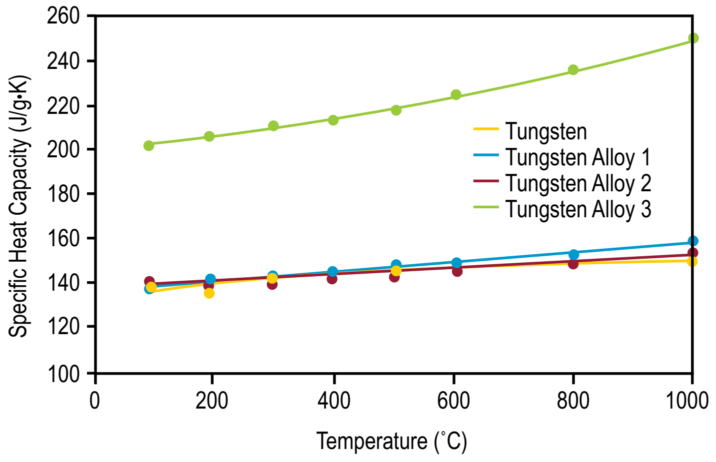
Applications

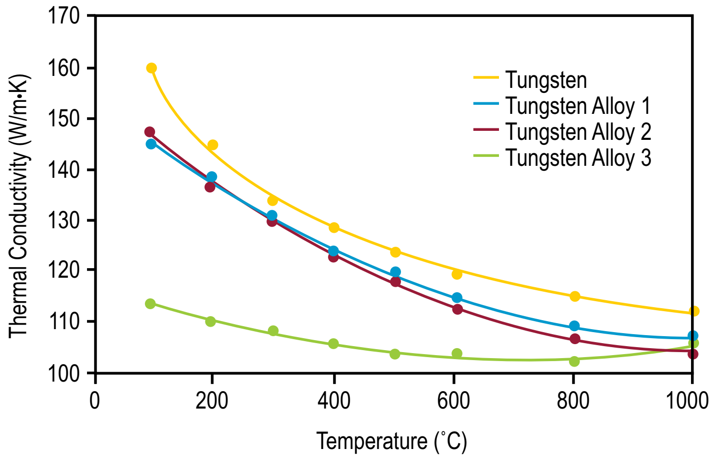
Tungsten Alloys

Tungsten alloys are valued for their high hardness, which makes them ideal for use in cutting or abrasion tools or rocket nozzles, applications which also require efficient heat transfer.

The data in these figures are the result of a study on various tungsten alloys, in comparison to a sample of pure tungsten. Specific heat capacity literature values for pure tungsten were used to derive reference data for testing and analysis. Thermal diffusivity and specific heat capacity data were measured on the alloy pieces using a DLF-1300 system.

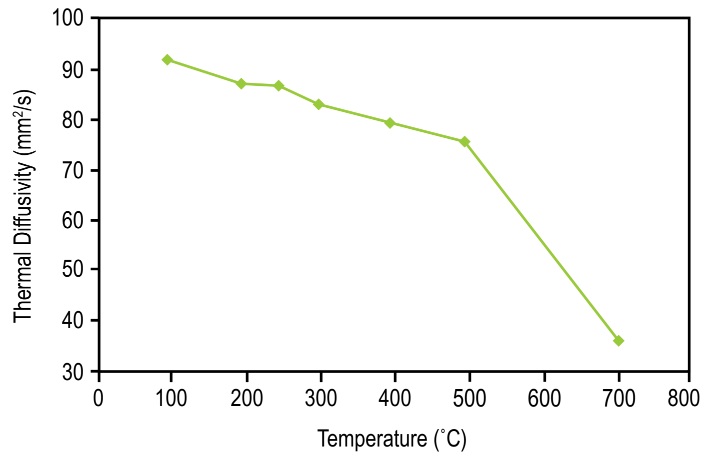
The data demonstrate the variance in thermophysical properties which can arise as a function of subtle changes in composition. Using the values for pure tungsten as a reference, two of the alloys show very little change in specific heat capacity or thermal conductivity. However, Tungsten Alloy 3 is observed to have a significant deviation in specific heat capacity. This is also found in the calculated thermal conductivity, where the alloy shows a difference in both absolute value as well as temperature dependence.





Aluminum Through the Melt

A sample's thermophysical properties can change dramatically as it undergoes a phase transition such as melting. As such, it is critical for instruments to accommodate a sample during these important processes. The data in this figure show the measured thermal diffusivity of an aluminum standard as it is heated through its melting point (660°C). Note the precipitous drop in thermal diffusivity as the sample transitions from solid to liquid.



Thermographite

Thermographite is a common reference material for thermal diffusivity by the flash method, as it is stable over a wide temperature range, and its thermophysical properties have been well-documented. The data in the figure show the measured thermal diffusivity of thermographite over the temperature range from ambient to 2800°C. At these elevated temperatures, measurement under an inert atmosphere (after evacuation) is critical to accurate thermal diffusivity results. The DLF-2800 system provides both the temperature range and environmental control required for these challenging conditions.