Optical setup for TDTR measurements at Fraunhofer IPM. This is where the thermal conductivity of thin films can be determined effectively, inexpensively and quickly.

Fraunhofer IPM

Measuring the thermal conductivity of thin films

Time Domain Thermal Reflectance (TDTR)

In many high-tech products, materials formed of thin layers just a few nanometers or micrometers thick are deposited on a substrate, where they perform specific functions. Precise knowledge of the thermal conductivity of these materials is essential for many applications. However, the thermal conductivity of thin-film materials generally differs significantly from the thermal conductivity of the corresponding bulk material. This is why dedicated measuring methods are required for characterizing thin films.

Effective, inexpensive and fast

The time domain thermal reflectance (TDTR) method provides an effective, inexpensive and relatively fast method for measuring the thermal conductivity of thin layers. Working on the basis of a pump-and-probe process, it uses two laser beams with different beam paths. Firstly, a pump beam is directed onto the surface of the sample, which is heated as a result of absorbing some of the beam power. The heat diffusion and temperature on the surface of the sample depend on its properties, in particular the thermal conductivity of the individual layers. The reflectivity, i.e. the proportion of the laser beam that is reflected from the surface of the sample, is influenced by the temperature. This means that the surface temperature can be determined by a probe beam that falls onto the sample surface after the pump beam with a time delay. The reflected probe beam consequently provides information about the surface temperature of the sample and its thermal properties. The reflected probe beam falls on a photo diode, allowing to retrieve the measurement data. A mathematical model is fitted to the acquired measurement data and used to determine the thermal conductivity of the layer in question. The depth of analysis of the method is typically between 100 and 2000 nm, depending on the thermal conductivity of the sample.

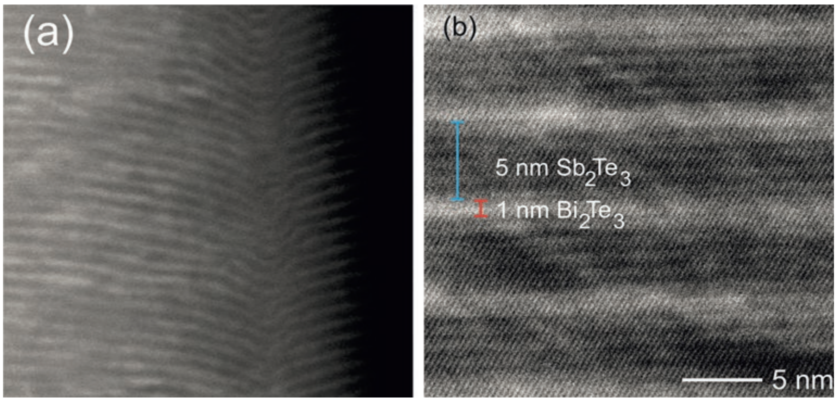
Suitable for a wide range of materials

The TDTR method can be used to characterize both individual layers and multilayer coating systems with layer thicknesses spanning from a few nanometers to a few micrometers or

Measurement services

We analyze the thermal conductivity of your materials.

Don't hesitate to get in touch!



Superlattice layered stacks made of the thermoelectric materials Bi_2Te_3 / Sb_2Te_3. TDTR measurements have proven that these nanoscale superlattices are capable of significantly reducing thermal conductivity in comparison to homogeneous materials.

millimeters. It is also possible to determine the thermal conductivity of bulk materials. Generally speaking, a wide range of materials can be measured, from polymers to ceramics and metals or glass.

The sample is very easy to prepare, as a thin Al layer simply needs to be deposited before the measurement is carried out, without the need for any further structuring. Measurements can be carried out in a wide temperature range from room temperature up to temperatures around 400 °C to 500 °C. The maximum achievable temperature depends on the sample.

Application examples

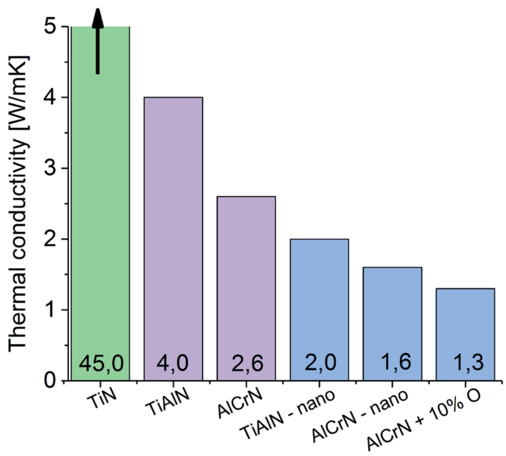
Thermoelectric thin films

The performance of thermoelectric devices is dependent on the ratio of electrical to thermal conductivity. The possibility of using nanostructures to lower the thermal conductivity of thermoelectric materials is currently being investigated. One example is the creation of stacks of layers with thicknesses in the nanometer range, which are known as superlattice systems (see fig. at the top of the page). Here, the TDTR method was able to demonstrate that superlattices of this kind can reduce the thermal conductivity of the layer system by more than 50 percent.

Hard coatings

To minimize wear and corrosion, machining tools are protected with a hard coating, such as titanium nitride (TiN). During use, these tools are often exposed to high temperatures. In order to understand how the protective layers and tools respond to such temperatures and to optimize these layers, one must be familiar with their thermophysical properties such as thermal conductivity. However, this information is rarely documented for the deposition techniques used. We used TDTR to determine the thermal conductivity of various coatings during a recent collaboration project (figure on the right).

Thermal conductivities of various hard coatings measured using TDTR



F. Barthelmä, H. Frank, M. Schiffler, PVD-Hartstoffschichten zur Zerspanung hochfester Werkstoffe, WOMag WOTech Technical Media, 2016, DOI: 10.7395/2016/FrankH1

Compared to compounds of two elements such as TiN, AlN and CrN, the thermal conductivity of solid solutions of three elements such as TiAlN and AlCrN is lower by orders of magnitude. Adding nanostructures and oxidation further reduces thermal conductivity.

Contact

Dr. Markus Winkler
Project Manager
Phone +49 761 8857-611
markus.winkler@ipm.fraunhofer.de

Fraunhofer Institute for Physical Measurement Techniques IPM
Georges-Köhler-Allee 301
79110 Freiburg, Germany
www.ipm.fraunhofer.de/en