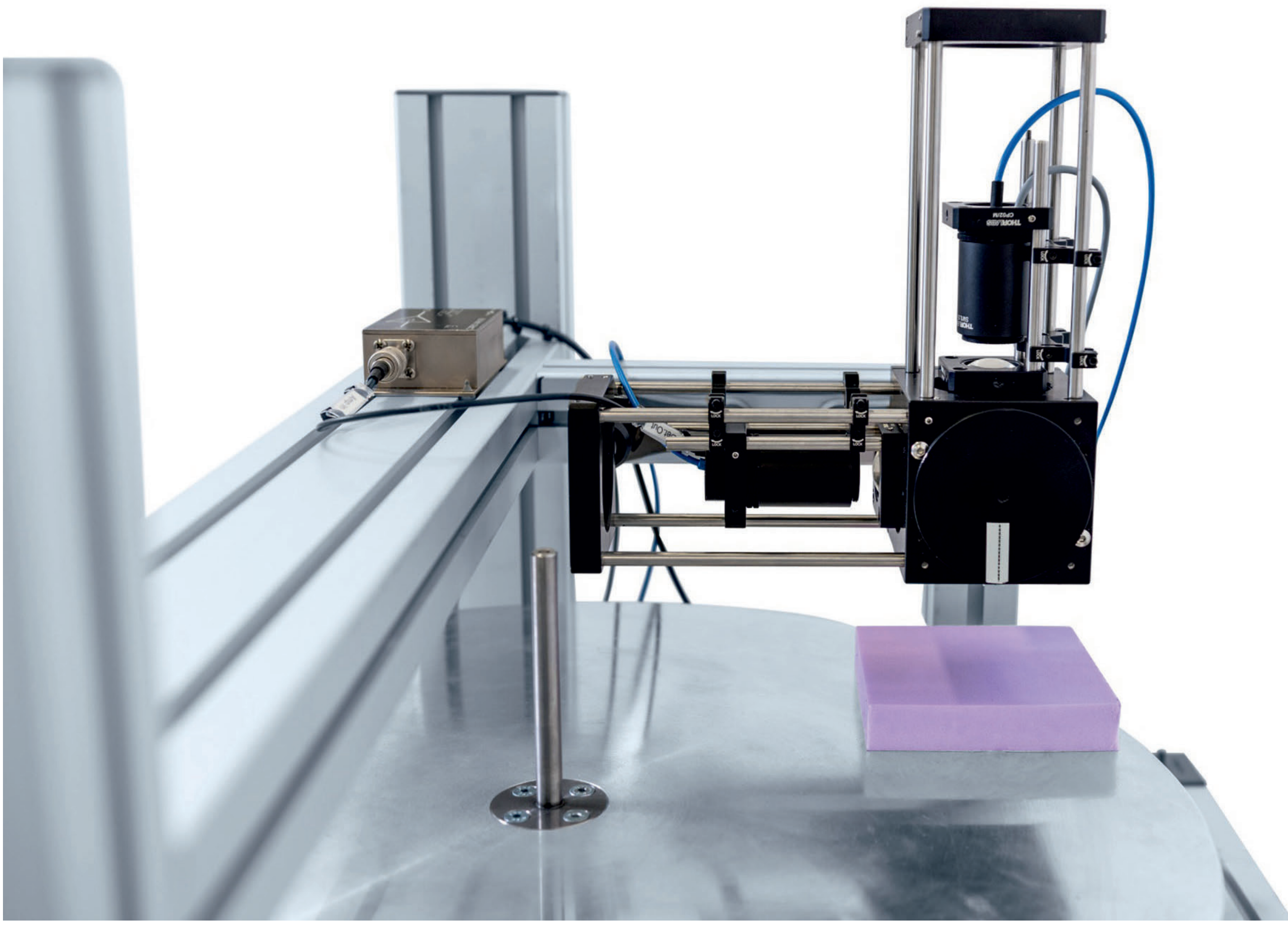
Contactless Testing of Packaging

Comparison of Terahertz- and Microwave-Testing

Terahertz and microwave methods offer a wide range of applications for testing of plastic packaging. Already established wall thickness measurements and defect detection are now joined by a wealth of other possible applications that promise process reliability and cost efficiency. Both systems show different strengths and are suitable for different applications.



The testing of foamed products is becoming increasingly important in the packaging sector. THz measurement technology can be used to determine cell size as well as cell size distribution and local bulk density of foams © SKZ

For several years now, terahertz and microwave methods in demand for the non-destructive testing of plastics. Located in the frequency ranges between infrared and radio waves (**Fig. 1**), these non-contact methods offer properties that make them suitable for a wide variety of testing tasks. Excellent depth resolutions, the possibility to investigate spectral information, large penetration depths in many polymers and the possibility to measure with one-sided component access are among their main advantages. Furthermore, the non-ionizing radiation allows operation without the need for elaborate protection and safety measures. Applications for these techniques can be found in compounding, injection molding, extrusion, additive manufacturing, welding and bonding, as well as on the final product. These include, for example, the determination of layer thicknesses on a micro to decimeter scale, the detection of defects caused by

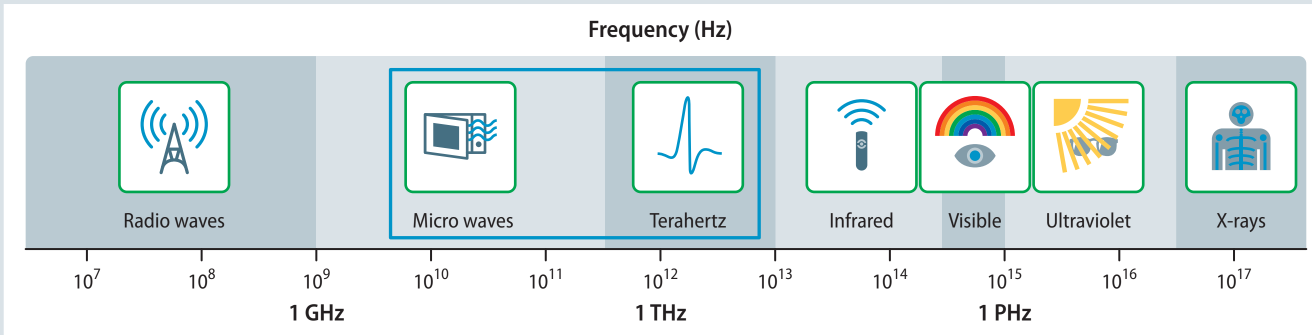


Fig. 1. The frequency range of terahertz and microwave technology lies between that of radio wave-based systems and that of infrared and UV light-based systems Source: SKZ; graphic: © Hanser

production and application, the characterization of foams with regard to cellular structure, the determination of moisture content or the description of the melting and solidification behavior of plastics. Thus, there are numerous possible applications suitable for the packaging sector, which will be described in the following.

Differences between THz and MW

Despite many common benefits of terahertz (THz) and microwave (MW) technology, a closer look reveals several differences besides the emitted wavelength: THz radiation is usually generated optically using ultrashort pulse lasers and semiconductors whereas MWs are generated purely electronically. The optical systems realize very large frequency bandwidths of several THz and thus very short pulse widths, which enables very high longitudinal resolutions. These make it possible to characterize products made up of several layers with individual layers in the µm range, which can often be found in packaging foils. However, optical THz measurement systems can be sensitive to environmental influences such as dust, temperature fluctuations or vibrations.

Fully electronic MW systems, on the other hand, are more robust with respect to the industrial environment, allow higher measurement speeds in the multi-digit Hertz range and are significantly more cost-effective. The main disadvantage is the inability to obtain spectral information, for example to identify materials. The lateral resolution of both systems, which decisively determines how large a structure, e.g. in the form of a defect to be detected, must be in order to be reliably detected, is in the (sub)millimeter range.

Saving Costs and Resources by Inline Testing

One of the most common applications of THz and MW technology in non-destructive testing is the determination of wall and film thicknesses. For these tasks, measurement rates lie in the multi-digit Hertz range and resolutions are typically to be found in the micrometer range. The inline measurement of film thicknesses during blow molding or calendering makes it possible to directly and reliably detect any potential deviations from a target value. This helps to maintain quality standards and can contribute to cost and resource savings as well as to an optimized process control. During the measurement process, the propagating electromagnetic wave is reflected at interfaces of different densities and subsequently detected by the sensor. Knowing the propagation speed and measuring the reflections over time allows to deduce the traveled distance and thus the respective coating thickness (**Fig. 2**).

Until a few years ago, for thickness measurements ultrasonic methods were used almost exclusively. However, these require a coupling medium between the sensors and the measured object. The peripheral equipment necessary for the supply of this medium is subject to wear and tear and hence requires recurring maintenance. Furthermore, the determination of thicknesses in ultrasonic technology is strongly temperature-dependent, which is not the case with THz and MW systems. In addition to the measurement of wall thicknesses of simple geometries, these technologies have recently been advanced so that more complex topologies, such as those in structured films, can now be measured, too. Thanks to such current developments, better and better systems with high »

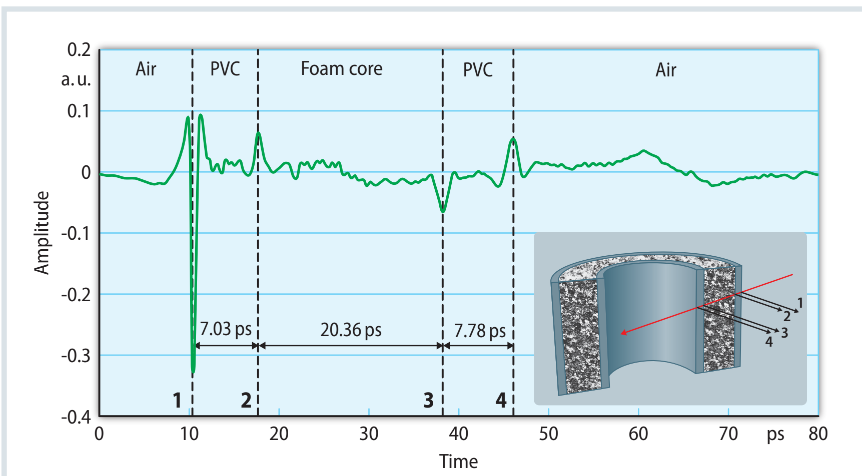


Fig. 2. Principle of thickness measurement: interfaces of different density lead to reflection of terahertz and microwaves. By measuring the temporal behavior and knowing the material-specific propagation speed, the distance traveled and thus the thickness can be inferred Source: SKZ; graphic: © Hanser

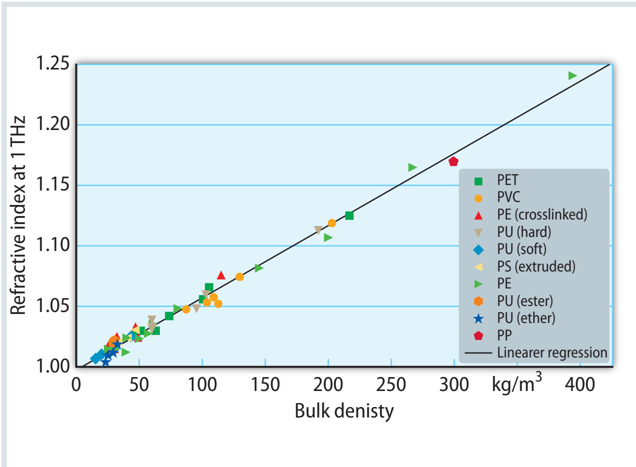


Fig. 3. Relationship between the refractive index, which can be determined in real time and inline, and the bulk density for various expanded polymers: since the frequency bandwidth is wider for THz systems than for MW systems, the former are more suitable for testing foams Source: SKZ; graphic: © Hanser

repeatability in the submicrometer range are becoming market-ready.

THz-Systems Advantageous with Foams

To date, the testing of foams is much less common in industry than the measurements of thicknesses. The former, though, is becoming increasingly important not only in the construction domain but also in the packaging sector (**Fig. 3**). Compared to the methods conventionally used for cell sizing, computer tomography, digital image evaluation and microscopic measurement of sections, THz systems allow a determination of parameters directly inline during extrusion. MW systems can be used in the same way, although for technical reasons the frequency bandwidth is not as wide as that of THz systems. This frequency bandwidth is however necessary for the proper interpretation of cell size-dependent scatter effects which in turn are a prerequisite for the calculation of cell size distributions. MW measurement thus cannot yield these distributions and only allow statements about the average cell size. Furthermore, the local bulk density can be exactly determined with both THz and MW systems. For this purpose, the travel time of the waves is calculated as a measure of the material-specific refractive index of the foam structure. Based on an experimentally determined correlation between the bulk density and the refractive index, the local bulk density can finally be inferred directly in the process and in real time.

Reliable Recognition of Defects in Packaging

The leak tightness of packaging is an essential quality criterion for many industries, such as in the medical and the food sector. In addition to the permeation properties of the packaging materials used, force-fit and form-fit bonds of different packaging parts are essential. These are significantly influenced by defects caused by production irregularities, such as foreign material inclusions, blowholes, cracks or delaminations, or a lack of adhesion between adjacent interfaces. The detection of such defects is possible using THz as well as MW systems either in the form of a 100% production control or as a random sample test in the laboratory.

In principle, a defect must have a different absorption behavior (regarding

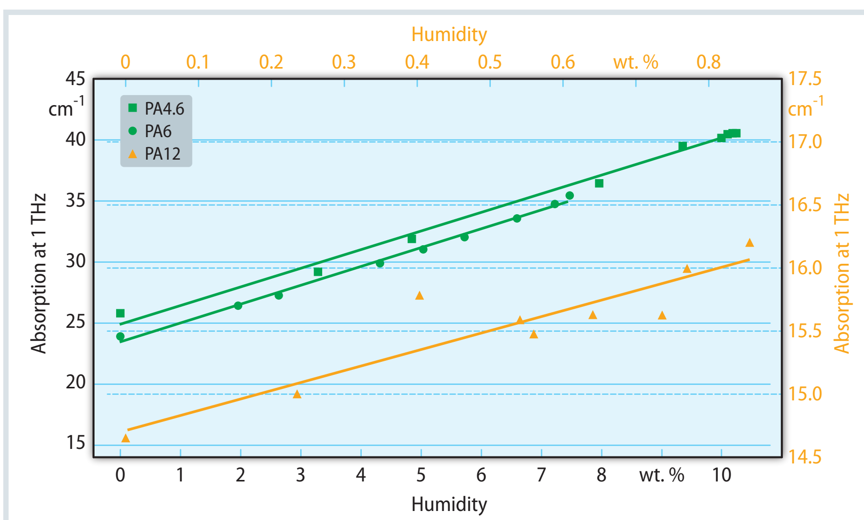


Fig. 4. THz and MW measurement techniques can be used to determine the moisture content of polymers. MW systems are particularly suitable for this purpose Source: SKZ; graphic: © Hanser

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- Read the German version of the article in our magazine ***Kunststoffe*** or at ***www.kunststoffe.de*** the incident electromagnetic wave) or a different refractive index than the surrounding material in order to be identified as such. Often, the depth of the defect in the component plays a subordinate role in defect detection, whereas its size decisively determines the effect on the product. On the systems engineering side, the inspection frequency is therefore of decisive importance. The higher the frequency, the smaller the resulting radiation-wavelength and the smaller the structures that can still be resolved (by imaging). For this reason, (high-frequency) THz systems with resolutions in the one- to two-digit micrometer range are often better suited for defect detection in packaging than (lower-frequency) MW systems with resolutions in the (sub)millimeter range.

Moisture and Filler Content: Further Applications for the Testing Methods

Other areas of application for THz and MW methods are manifold. By measuring the radiation's absorption, for example, it is possible to determine the moisture content of plastics, which is particularly relevant for hydrophilic materials (**Fig. 4**). Since the measurement at individual frequencies is sufficient for this purpose, and thus no large frequency bandwidth is required, less expensive electronic MW systems are suggested for this type of measurement. Moreover, the filler content of plastics can be determined quantitatively by determining the refractive index. Particle sizes can be determined by measuring the frequency-dependent absorbance (**Fig. 5**). For both applications, as in the identification of materials, a wide frequency bandwidth is advantageous, so that THz systems have proven to be more suitable here (**Fig. 6**). In addition to these examples, analyses of the orientations of molecular chains, particles and fibers as well as the determination of the degree of melting or of the solidification of plastics are also possible and can be helpful to describe welding and bonding processes relevant to packaging.

Testing technologies that rely on THz and MWs offer users a great deal of untapped potential. Especially the non-contact and inline usability as well as good resolutions and possibilities for spectroscopic analysis result in a wide range of applications in the packaging sector. SKZ – Das Kunststoff-Zentrum, a member of the Zuse Association, is a leading institution in this field, focusing on industry-oriented and practice-relevant research work. Current developments there aim, for example, at the transfer of punctually measuring methods into tomographic, i.e. three-dimensional, imaging. Many of the described applications in this article are on the threshold of commercialization, so that SKZ offers industrial implementation in cooperation with system manufacturers or end users. ■

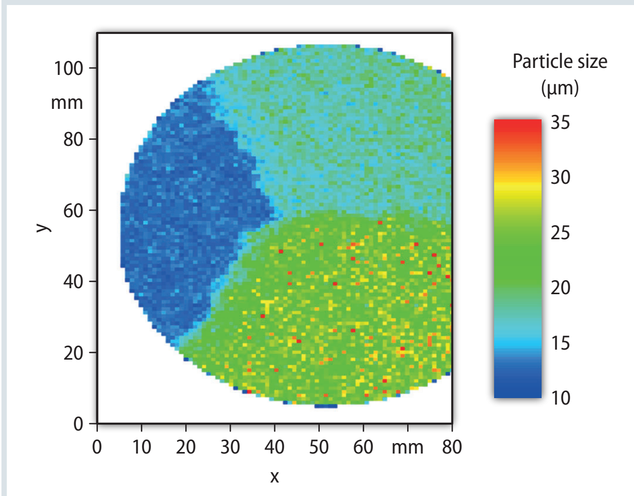

Fig. 5. Measuring the frequency-dependent absorbance allows conclusions to be drawn about particle sizes. A wide frequency bandwidth is an important criterion for this purpose Source: SKZ; graphic: © Hanser

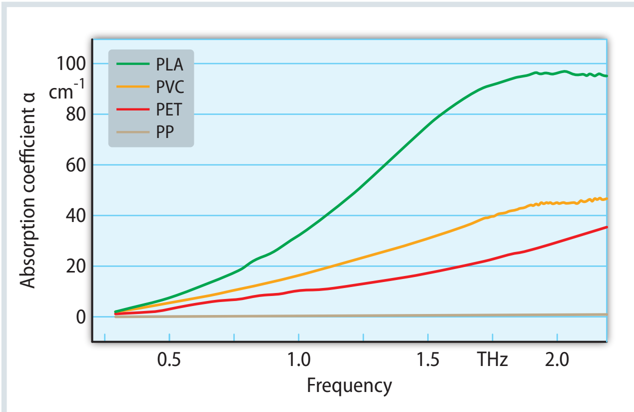

Fig. 6. THz and MW methods can also be used for the identification of materials Source: SKZ; graphic: © Hanser