Measuring Products & Substrates with Terahertz

David W. Pond, Chief Operating Officer
Automation and Control Technology, Dublin, OH, USA

Abstract

Producing a substrate for any rigid packaging application with a uniform and consistent structure is the route to maximizing the package properties with the lowest cost. In order to meet this challenge, many new packaging materials are being developed with multilayer structures in order to minimize the use of higher cost materials. Terahertz technology now allows measurement and can ultimately provide a method to control up to four layers to help maintain the package production at the lowest cost.

Introduction

The goal of this paper is to acquaint the reader with the capabilities of making measurements with a Terahertz Sensor, and to acquaint the reader with the principles, capabilities, and limitations when using Terahertz to make product or substrate measurements. The use of Terahertz technology is growing fast because of a number of key attributes:

1. Terahertz is a safe alternative to nucleonic technology. There is no radiation present or need for regulatory compliance issues.
2. Terahertz measurement is generally not dependent upon the intensity of the signal, as in any radiation based measurement technique, but is based upon the time between significant events.
3. Under the right conditions, Terahertz can provide more accurate measurements than a nucleonic sensor.
4. Terahertz has the ability to measure layers within a product, unlike a single measurement received from other traditional devices yielding only total basis weight, or total thickness.

Technology Description

Time Domain (TD) Terahertz (THz) Sensors emit and detect a very narrow (<1 picosecond [ps]) electromagnetic (EM) pulse that forms photons in the THz frequency range. The THz frequency range lies between microwaves (0.1 THz) and far infrared (IR) (10 THz). TD-THz sensors measure the electrical field strength of the EM photon pulse as a function of time. Most dielectric materials are transparent in the region of interest with TD-THz (0.05–3 THz). Plastics (regardless of color), paper, textiles, dry wood, packaging materials, rubbers, foams, non-polar liquids (such as oils), paints (including low observable "radar absorbing") and other coatings are all transparent to THz wavelength photons.

Polar liquids (such as water and alcohols) are strongly absorbing over the THz frequency region. The EM photon pulse is also non-ionizing and thus safer than sealed radioactive source techniques.

The THz pulse is low energy (less than 1 microwatt [μW]) and can be focused, reflected, and treated essentially in the same manner as any pulsed photon (light) source. After this photon pulse has interacted with matter (transmission, reflection, and scatter), the changes in the pulse lead to two primary methods of analysis, spectroscopic and Time-of-Flight (ToF). Spectroscopic methods of investigation are possible with THz. The transformation of the TD-THz data using a Fourier function to better understand the time and frequency domains of the data allows time and spectroscopic analysis. The second common method of analysis is to directly study the TD data by measuring changes in the ToF of the photon pulse as it interacts with matter. This is the technique we will focus upon.

Analysis of ToF for the THz pulses can be used to determine the basis weight (mass per unit area) of manufactured products. A material's ToF value is found in the following manner: when photons transmit through a material, the transit time of the photon will be increased due to the increased refractive index (RI) of the material compared with the RI of photons in air or vacuum (~1).

The ratio of the velocity of photons in a vacuum to the velocity of photons in the material of interest defines the RI for that material. Because the velocity of the EM is less in a material, the amount of time required for the EM to transmit through the material will be longer. The difference in time between the EM pulses transmitting through the material, compared with the same transmission through air, although extremely small can be precisely measured with THz instrumentation. This difference is the ToF delay. This ToF delay (typically in ps) is calibrated against basis weight values for the sample material determined using laboratory measurements.

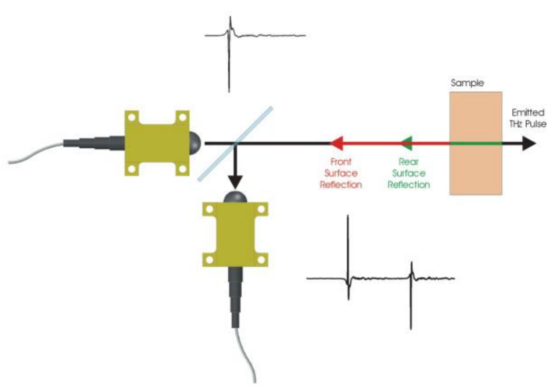
The THz method to measure a material's basis weight is to measure the RI that causes the increase of the ToF of the EM pulse as it transmits through the material of interest. This ToF value, which can be translated to an RI, is calibrated against accepted values of the material's RI and basis weight. Thus the THz method is a time-based measurement, as opposed to the amplitude attenuation-based measurement method of nuclear gauges.

The measurement of basis weight is the most common use for nuclear gauges in industry. A wide range of material basis weight values (5 grams per square meter (gsm) to greater than 100,000 gsm) can be measured with this single source THz instrument. The THz sensor directly measures the ToF increase due to the pulse passing through the material under test. Formally this increase in ToF is the volume of material in the beam path times the RI of the material at the THz frequency minus 1.

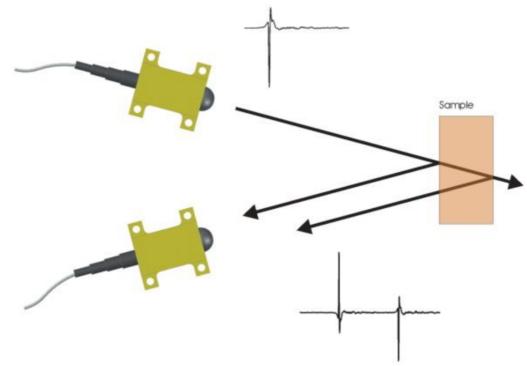
A nuclear gauge measures the amount of matter between the source and detector, which is most directly converted to basis weight. In circumstances where the material has a uniform density, the nuclear gauge measurement can also be correlated to physical thickness.

Most THz measurements are made in reflection, as this geometry simplifies the sensor configuration and reduces cost. Often, a fixed metal plate is installed behind the sample. The THz pulse, reflected off a rear metal plate, will have transmitted through the sample twice. This measurement mode is equivalent to double pass transmission and the measured ToF delay is therefore increased by a factor of two.

The use of a beam splitter in the reflection sensor allows the transmitting and reflecting THz pulses to remain collinear throughout the inspection (see Figure below).



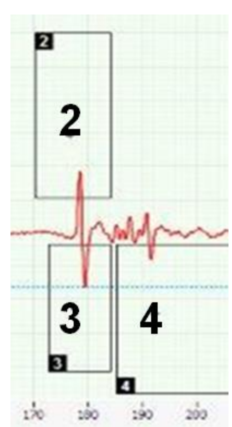
Therefore, the sensor operates best when aligned orthogonal to the inspection surface. However, for illustration purposes, an angle is often shown between the transmitter and receiver (see Figure below).



This display method helps to clearly separate the incoming and reflecting THz pulses and thus better illustrates the origin and timing of the reflection pulses.

Measurement Example of Two Layer Products

The following example is meant to convey the measurement principles in using the Terahertz sensor. The product used consists of two layers, one ~2 mils in thickness, and the second layer, ~66 mils thick. The composition is not relevant to this example, because Terahertz will transmit through many different types of material; it is only the approach of using a Time Domain sensor that is important to understand. The x-axis unit of measure in this example is time, and the relevant measurement is the time between peaks.



The first peak encountered by the Terahertz beam is found at ~177 ps from the start of the measurement area, shown as #2 in the chart to the left. This represents the first surface, and the peak indicates a change in the index of refraction from air to the start of product layer 1. The second relevant peak is #3, located at ~178 ps, and the final peak, #4 at ~192 ps, represents the surface of the far side of the product. By calculating the ToF for each layer, (i.e. #3 - #2, and #4 - #3) and applying the correct Index of Refraction for each layers type of material, both the thickness and basis weight for each layer can be reported.

These independent measurements are then reported to the gauging system, where displays as shown below are available for operator viewing, and as OPC outputs available to interface to line control systems.

There exists a plethora of displays available showing basis weight and thickness for each individual layer, or combined to show overall metrics. Because each layer is measured separately, control actions including line speed control for overall thickness, and diebolt outputs, to control the flatness of the product are commonly available.

Conclusion

Terahertz technology can and does provide measurement of individual layers within the current packaging spectrum, and can ultimately provide a method to control up to four layers to help maintain the package production at the lowest cost.

Additional References

Automation and Control Technology website contains more information and details of other applications for the Terahertz technology.

http://www.autocontroltech.com/
http://www.autocontroltech.com/news.htm
http://www.autocontroltech.com/newstwo.htm