Application Note

Quality Control of Chocolate Products with THz Imaging

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Introduction

Food industry is bound by strict safety regulations in terms of production environment and food quality. Food products need to pass rigorous quality tests and contamination of any kind has to be excluded. A controlled clean environment is the most important rule in order to comply with the high safety standards. Yet, during the fabrication process still contaminants might fall into the bulk or unpacked product. Potentially harmful objects such as pieces of plastic, wood, glass, stone or metal need to be detected and the affected products have to be removed from the batch. Classical inspection methods such as random sampling are insufficient, destroy the inspected sample and decrease the yield if an entire production charge needs to be rejected. Metal particles can be detected easily by a metal detector. However, this detection method has poor spatial resolution, and it is not possible to localize the impurities accurately enough. Detection of non-metallic objects like stones occurring in natural products, or glass and plastic particles from fabrication tools and machines is even more challenging.

We present a novel spectroscopic technique which uses terahertz (THz) radiation and has high potential to detect contamination in food. The frequency of the electromagnetic THz spectrum is in the range of 0.1 to 10 THz (100 GHz to 10,000 GHz), with corresponding wavelength of 3 mm to 0.3 mm. Unlike hazardous x-ray radiation, THz-waves are non-ionizing and harmless for food products and for human beings. They empower a non-destructive and user-safe testing method for the food industry. Dry foodstuff or products made of non-polar substances, such as e.g. fat or oil, are transparent in the THz range and ideal candidates for THz quality inspection. High water content, however, might obscure the measurement method since water is strongly absorbing THz radiation. First inspection tests of chocolate bars show that these are relatively transparent for THz waves since their main ingredient is cacao butter and the water content is low [1]. In this application note we present THz inspection as a contact-free and safe method to test contamination of chocolate products. By scanning the THz measurement spot over the sample, a THz image is produced and impurities can be located easily.

Materials and Methods

For THz imaging of chocolate bars or similar products we have used a THz time-domain spectroscopy (TDS) system assembled in transmission geometry. As proof of principle, the geometry of the test sample is simply a plain chocolate bar.

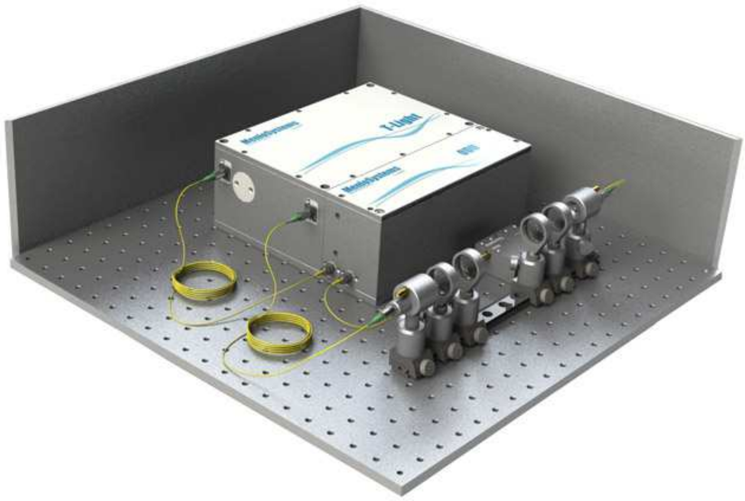

Fig. 1: *TERA K15 THz-TDS system assembled in transmission geometry*

Menlo Systems' fiber coupled TERA K15 (Fig. 1) or free space TERA K8 THz time-domain spectrometers are ideally suited for the purpose of food characterization. Depending on the requirements, the systems can be arranged in transmission or reflection geometry. In particular the fiber coupled TERA K15 offers high flexibility with respect to the measurement geometry. The spectral range of the systems is exceeding 3.5 THz, and the temporal scanning range of more than 300 ps is sufficient to measure thicker samples. The novel high-power THz antenna technology used in the TERA K15 is a plus for thick or highly absorbing samples.

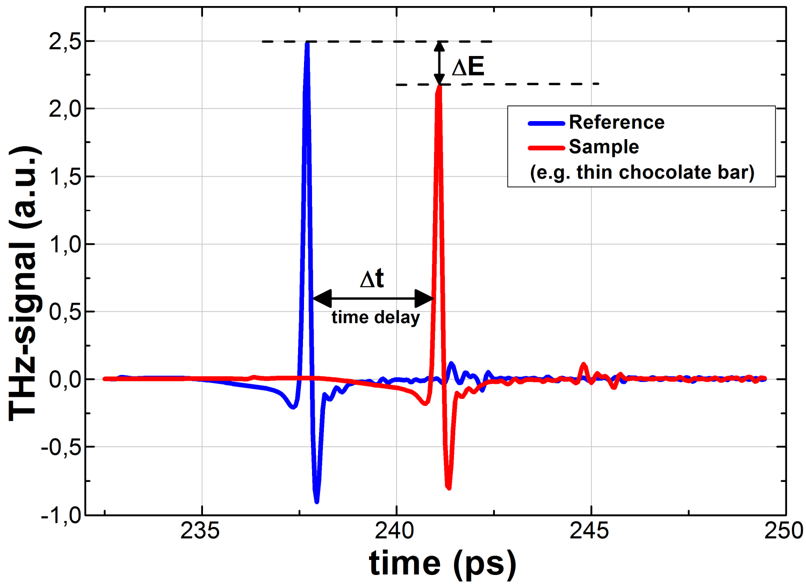

Fig. 2: *THz pulses measured in air reference (blue) and in a thin chocolate sample (red). The temporal position is shifted and the amplitude is decreased after the chocolate.*

In a THz TDS measurement, the electrical field of THz pulse is scanned in time, such that one obtains the information on both, the amplitude and phase of the THz electric field (Fig. 2). After the system has been characterized in a reference measurement, the sample is placed into the focal plane of the THz beam. When a THz wave passes through a sample or is scattered at its boundaries, the recorded signal is shifted in its time (Δt) and has a decreased amplitude (ΔE) with respect to an air reference measurement. By carefully evaluating these changes, one can calculate the refractive index and the absorption coefficient of the sample.
Figure 2 shows the THz pulse measured in air (reference, blue) and with a chocolate bar (sample, red). With the sample placed in the THz focus the arrival time of the pulse is delayed (Δt) and the signal amplitude is smaller (ΔE). This is because dispersion and absorption in chocolate are significantly different than in air, but also surface reflections and refraction effects contribute to the signal decrease.

In order to create an image, the chocolate bar is moved through the THz focus, e.g. using an automated unit, and a THz pulse is measured at the different sample positions. The speed of measurement depends on the density of the recorded data points, i.e. the image resolution. The THz material parameters of the contaminants are different from those of pure chocolate. Typically, they have a higher absorption coefficient. The resulting decrease of THz transmission can also be described as an increased effective absorption coefficient of the chocolate-impurity mixture in comparison to pure chocolate. By plotting the measured THz signal over the surface of the sample the changes can be made visible in the THz image. In summary, pure chocolate shows higher transmission than contaminated areas.

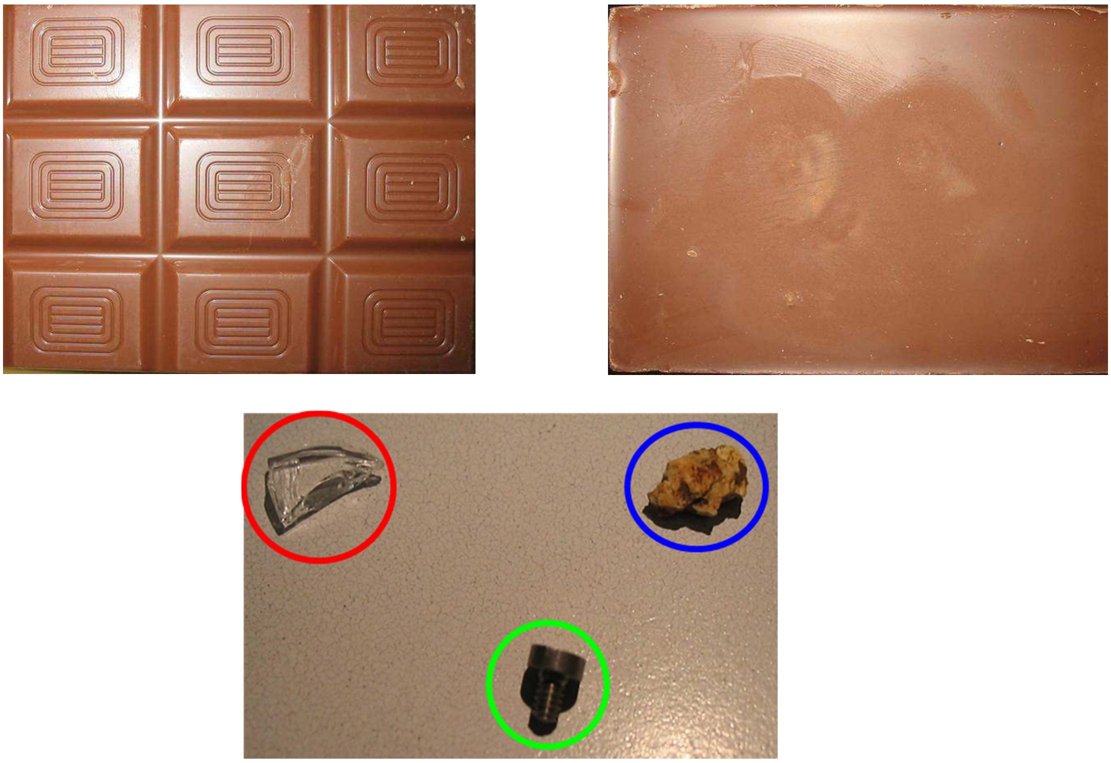

Fig. 3: *Front and back side of chocolate bar after preparation with a glass splinter, a stone, and a metal screw.*

To demonstrate the enormous potential of THz spectroscopy for chocolate testing we prepared a sample by inserting a glass splinter, a stone, and a M2 metal screw into a chocolate bar (Fig. 3). The unwrapped chocolate bar was imaged using a THz TDS setup. Nowadays, chocolate products are commonly wrapped in plastic foil which is transparent for THz radiation, and one can in principle also investigate already packed chocolate products. Aluminum wrapping foil or other metal packaging would of course absorb the THz waves and make the measurement impossible.

The wrapping process itself represents another weak spot of the production chain. In order to investigate if such contamination can also be detected, we prepared a second sample by inserting a stone between the front side of a chocolate bar and its original plastic package.

Results and Conclusion

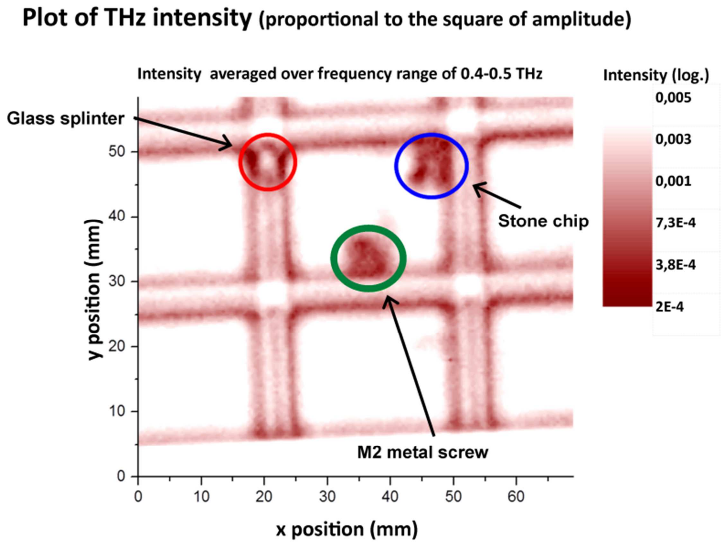

Fig. 4: *THz intensity image of a chocolate bar with different contaminating particles (compare Fig. 3).*

The spatial scan of the transmitted THz pulse through the first chocolate sample is depicted as an intensity image (Fig. 4, the intensity is proportional to the square of the electric field amplitude). All objects can be clearly located on the image. The typical ridge structure of a chocolate bar with thickness variations where edges act as scattering surfaces is clearly recognizable in the THz image, at the same time the difference between contamination and a ridge edge can be distinguished.

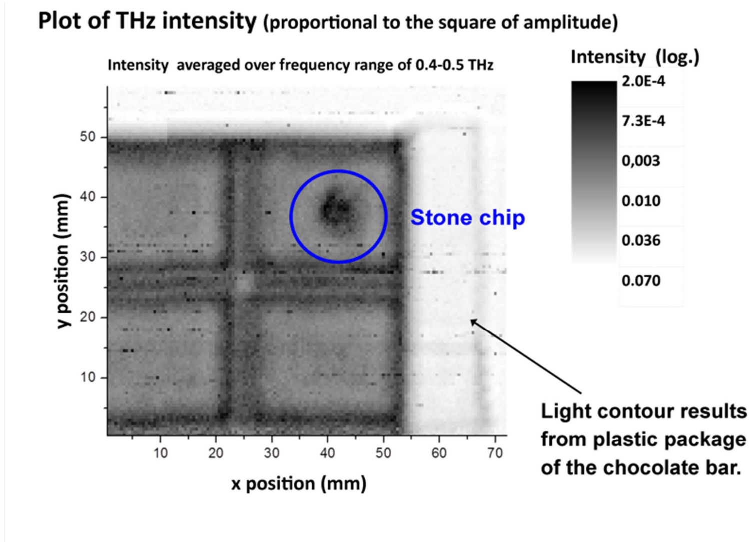

Fig. 5: *THz intensity image of a chocolate bar wrapped in plastic foil. The dark area in the upper corner is resulting from the stone.*

The feasibility of the THz inspection method for wrapped chocolate bars was tested with the second prepared sample containing a stone inside the package. Figure 5 shows the imaged chocolate bar through its plastic wrapping. The evaluation of the image is equivalent to that of figure 4. The stone is visible as a dark feature in the upper corner of the chocolate bar and the plastic foil can be seen as a surrounding light shadow.

Chocolate products with a more complex inner structure, e.g. containing fillings like waffle or other multiple layers, can be investigated in an optimized THz TDS setup. Depending on the task, a tailored evaluation algorithm needs to be used for data evaluation. A commercial alternative might be the TeraLyzer software, an advanced analysis tool distributed by Menlo Systems. It extracts material parameters like the refractive index and the absorption coefficient from the spectral phase and amplitude information, and it calculates the thickness of thinner layers. Other chocolate products containing liquids can be investigated in a THz system in reflection geometry.

In summary, THz time-domain spectroscopy is a powerful, contact-free and non-destructive technique to inspect chocolate products for contamination. With THz radiation it is possible to detect objects of various materials. Even products which are wrapped in plastic packaging can be investigated, so that it is possible to control the product quality at different stages of the production line. The real strength of the method, however, lies in its simplicity since it is quick and does not need any complex mathematical conversion of the measured data to detect contaminants.

Further reading

[1] Christian Jördens, Frank Rutz, Martin Koch: Quality Assurance of Chocolate Products with Terahertz Imaging; European Conference on Non-Destructive Testing, 2006 – Poster 67