Inspection of Packaged Integrated Circuits using Terahertz Radiation

Andreas Fritz
CTR Carinthian Tech Research AG
Villach, Austria
andreas.fritz@ctr.at

Thomas Arnold
CTR Carinthian Tech Research AG
Villach, Austria
thomas.arnold@ctr.at

Abstract— **A non-destructive, non-contact inspection system for packaged integrated circuits using terahertz (THz) radiation is tested. Our results show that we are able to reconstruct the internal structure of the IC, like the microelectronic chip and the interconnections. Due to the limitation of the system and the wavelength of THz radiation the fine bonding wires could not be detected. However, we show that the THz technology will be a valuable tool for the automatic online inspection of packaged integrated circuits.**

Keywords-terahertz; Time domain spectroscopy; Wavelet transformation; Wavelet denosing; packaged integrated circuit inspection

I. INTRODUCTION

In the electromagnetic spectrum, especially between microwaves and infrared frequencies lies the Terahertz (THz) radiation. This area refers as the “terahertz gap” and is located between 300 GHz and 30 THz. Radiation with 1 THz has a wavelength of 300 µm, a period of 1 ps, an equivalent temperature of 47.6 K, and a photon energy of 4.1 meV. The field of application for THz radiation is broad. Compared to X-Rays this radiation is not ionizing and considered safe for both the sample and the operator. Because of the wavelength THz waves are transparent to most dry dielectric materials (e.g. paper, plastic, and wood). With sub millimeter spatial resolution THz waves are sufficiently short for different non-destructive evaluation applications. Another application for THz radiation is spectroscopic fingerprinting which could be combined with imaging providing both profile and composition information of the target. Also the dispersion and absorption of materials can be determined. [1]

Metal and highly doped semiconductor materials are excellent reflectors; therefore this technology is a valuable tool for a non-destructive inspection of packaged integrated circuits. Currently this chips are tested offline and on sample basis by human operators. For these test the IC has to be connected which may also lead to failures. Furthermore, in some test the IC has to be destroyed. [2]

II. MEASUREMENT SETUP

The measurement setup consist of a fast time-domain THz imaging spectrometer (ZOMEGA,USA) with a frequency resolution less than 5 GHz and a spectral range from 0.1 to 3.5 THz. For the THz pulse generation a near infrared (NIR) femtosecond (fs) fiber laser (Toptica, Germany) with a second harmonic wavelength of 780 nm is used. The laser output power is greater than 140 mW and has a pulse width less than 100 fs. For imaging in reflection mode a two-axis imaging stage is used. Fig. 1 shows the THz setup in reflection mode with its corresponding beam paths.

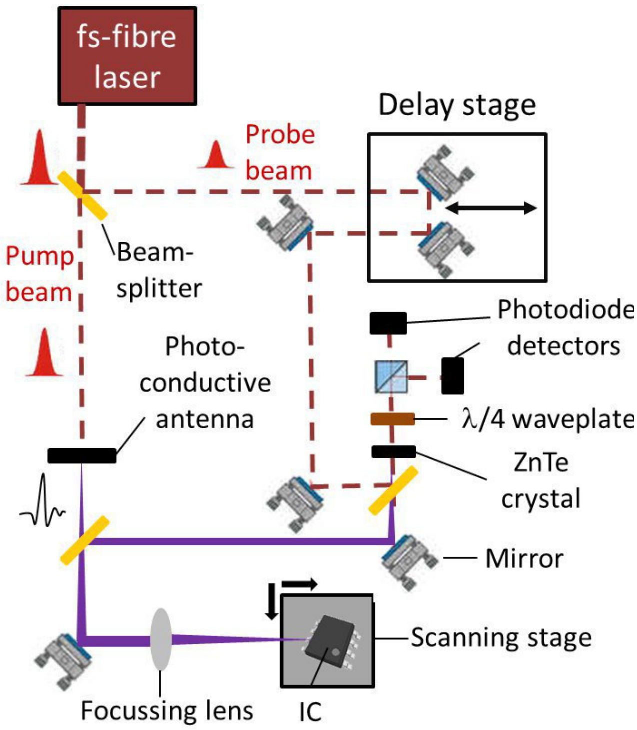

Figure 1. Schematic of the THz measurement system with corresponding beam paths. Dashed lines show the near infrared femtosecond fibre laser. Solid line represents the THz path.

A. THz pulse generation

For the THz pulse generation a photoconductive antenna is used. Here, electron hole pairs are created through the illumination of the femtosecond laser pulses. Due to an applied bias electric field across the antenna the photo-excited carriers are accelerated. This acceleration provides the basic physics mechanism to generate the THz radiation. [3]

B. THz pulse detection

To detect the THz pulse electro-optical sampling based on the Pockels effect is used. Applying an electric field for example on a zincblende crystal (ZnTe) leading to a change in the refractive index or the birefringence.

Detecting the change of the elliptical polarization of the probe beam, induced by the THz wave, lead to a net current between the two photo diodes. This net current is proportional to the amplitude of the electric field of the THz wave. [1]

III. Methods

For evaluating the acquired data the signal has to be enhanced. In the time domain this enhancement is done by using wavelet denoising.

A. Wavelet transform

The Fourier Transformation gives the spectral information in the frequency domain or the spatial information in the spatial domain. So there will be a loss of the spatial/time information when transforming in the frequency domain. To overcome this problem the Short Time Fourier Transform (STFT) with the drawback of a fixed window size with no multi resolution information of the signal will be used.

The wavelet transformation holds the property of multi resolution information through variable window size.

To get the time and frequency information simultaneously a mother wavelet is scaled and shifted.

$$W_\Psi(s,\tau) = \frac{1}{\sqrt{s}} \int_{-\infty}^{+\infty} x(t) \Psi\left(\frac{t-\tau}{s}\right) dt \qquad s,\tau \in R, s > 0 \qquad (1)$$

Equation 1 represents the wavelet transformation, where ψ is the mother Wavelet, s and τ are the scaling and shifting parameters, respectively. [3]

B. Wavelet denoising

For denoising the signal is transformed in different sub-Wavelet spaces concerning to the scaling parameter. At each sub-Wavelet space a threshold is applied and the afterwards the signal is transformed back into the time domain giving a denoised version of the initial raw signal. [4]

C. Refractive index

The refractive index describes how light or any other radiation propagates through a media. With the refractive index n and the time delay Δt the thickness of the sample can be determined. The thickness d of a sample is given by:

$$d = \frac{\Delta t \, c}{2n} \qquad (2)$$

where, c is the speed of light in vacuum. Because of using the THz system in reflection mode, the THz waves passes through the material under inspection two times. This factor of two must be taken into account. [5]

IV. Result

For our measurements we use an eight bin (DIL8) integrated circuit containing one microelectronic circuit chip. Fig. 2 shows a schematic diagram of the internal structure of the IC.

Figure 2. Schematic of the internal structure of the integrated circuit showing the 8 pins and the microelectronic circuit chip in the middle.

Once the signal is acquired it has to be denoised using Wavelet denoising. In Figure 3 the acquired raw data is shown in blue and the denoised version is shown in red. The difference is illustrated in green. As the figure implies, the main peaks are preserved while the noise is nearly fully removed.

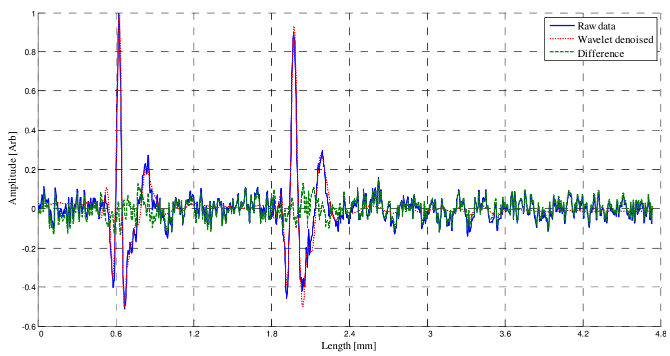

Figure 3. Raw data input in blue, the Wavelet denoised version in red and the difference of both in green.

Figure 4 represent the time domain signal of the reference (dotted green line) and the response of the microelectronic circuit chip (blue line) and the interconnections (red line). The first peak illustrates the top surface of the IC. Peak 1 is the response of the microelectronic chip and peak 2 of an interconnection. The small peaks at the end of the signal are the multiply reflection inside the IC. Those multiply reflection will be used in future work to determine the absorption and refraction index of the material under investigation automatically.

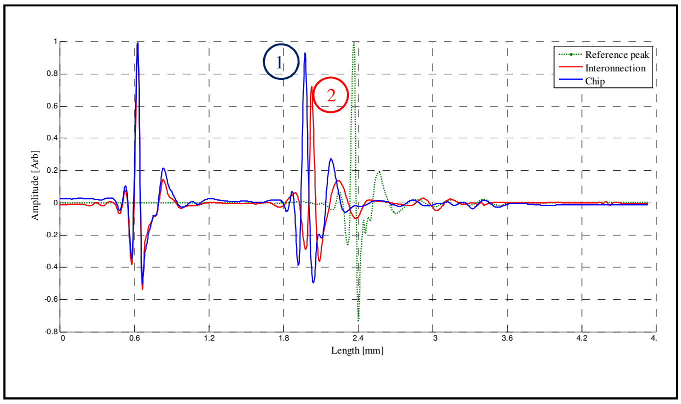

Figure 4. This plot shows the reference signal (green dotted line), the THz signal of the interconnection (red line), and of the chip (blue line). The first peak represents the top surface of the IC and the peak 1 and peak 2 the surface of the microelectronic circuit chip and the interconnection, respectively.

With the spatial and time information a 3D reconstruction of the internal structure is performed. Figure 5 shows the top and side view of the IC under inspection. The microelectronic circuit chip, as well as the interconnections can be seen clearly. The both metal surfaces on the left and right of the microelectronic circuit chip has no functionality for the IC. It may be used during the packaging process to hold the microelectronic circuit chip.

Based on equation (2) we calculate a refractive index n of the packaging material of 0.914. Taking the refractive index into account we measured a thickness of 1.52 mm. The microelectronic circuit chip is located 42.7 µm below the interconnections.

Because of the wavelength of the THz radiation the fine bonding wires could not be reconstructed. These fine bonding wires are used to connect the interconnections of the IC with the microelectronic circuit chip.

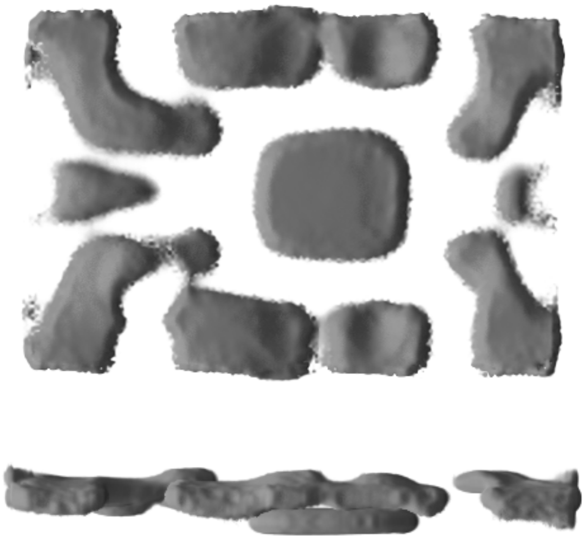

Figure 5. 3D reconstruction of the internal structure of the packaged IC with its interconnections and microelectronic circuit chip

V. Conclusion

A non-destructive, non-contact inspection system for packaged integrated circuits was investigated. Because THz radiation can penetrate through different dry dielectric materials we are able to reconstruct the internal structure of the packaged integrated circuit. Because of the spatial resolution of the system (depending on the wavelength and the imaging stage) we are at the moment unable to resolve the fine bonding wires which would be interesting for the semiconductor industry.

VI. Future Work

In future work the spatial resolution of the system has to be enhanced using super resolution approaches to improve the image beyond the diffraction limit.

Also to make the system more applicable for industrial applications the acquisition time has to be decreased. This could be done by using THz sensor arrays.

To achieve highly precisely depth values, a model of material (absorption and refraction index) will be implemented to determine the correct position of the structure within the packaged integrated circuit automatically.

Acknowledgment

The Competence Centre CTR is funded within the R&D Program COMET - Competence Centers for Excellent Technologies by the Federal Ministries of Transport, Innovation and Technology (BMVIT), of Economics and Labour (BMWA) and it is managed on their behalf by the Austrian Research Promotion Agency (FFG). The Austrian provinces (Carinthia and Styria) provide additional funding.

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