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High-frequency acoustic imaging with focused transducer for rapid micro echography of interfaces through buried structures non-perfectly planar

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The high frequency micro acoustic imaging (10MHz - 1GHz) reaches its limits when it is necessary to observe through absorbing or thick layers, not perfectly flat, at high frequency for a good resolution. The objective of this paper is to present a new method of acquisition and signal processing to image with high resolution buried defects through layers not perfectly flat and to reconstruct the topography and see possible delaminations.
Typically a displacement of the focused transducer is achieved to maintain a constant temporal position of the echo of the interface to be examined. This allows the creation of an image of the interface, but the acquisition time and complexity of the device is often prohibitive. This method, in the continuity of a paper presented at the 2010 CFA, does not use a hardware control of the transducer, but a software control.
Applications of this method allow the imaging of multilayers power electronics devices composed of stacks of conductive substrates or not conductive, with microelectronic circuits. Two types of representations are used: images and 3D reconstruction movies.

1 Introduction

In this paper we present a new micro acoustic acquisition method with focusing lens for nondestructive observation of interfaces in a thick substrate (with an important ultrasonic propagation velocity). As demonstrator, we use an assemblage of power modules with multi layers. Acoustic microscopy uses focusing sensors that provide a good lateral resolution depending of the frequency. As the attenuation generally increases with the square of frequency [1], in high frequency, the signal is in the noise when the distance to observe defects in depth is too high.

The objective is to obtain the signal from an analogical acoustic microscope with a high-speed digital sampler. We save data without numerical specific signal processing and then apply a post-treatment on raw data digitized and stored in a file. This process will allows us to image with high-resolution surface and depth of the samples analyzed for the visualization of defects in buried interfaces and to rebuild their topography as well as possible cracks and delaminations. Two types of representations are used: images and 3D reconstruction movies.

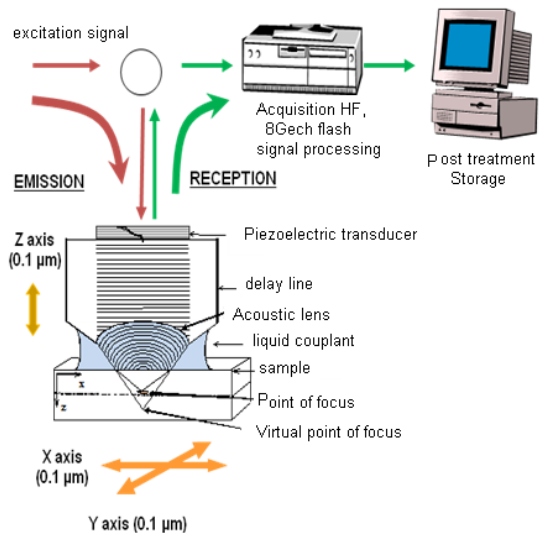

Fig. 1 : Schematic illustration of a scanning acoustic microscope in reflection mode

2 Methodology for the acquisition of acoustic images

2.1 Principle of high frequency scanning acoustic microscope

Figure 1 shows the basic principle of the acoustic microscope. It includes an ultrasonic generator consisted of a piezoelectric transducer. It converts the electrical signal into an incident acoustic signal through, for instance, a thin layer of zinc oxide: a few microns thick, for GHz frequencies or few ten microns for 100MHz frequencies. The piezoelectric layer is deposited on one side flat and polished to a small cylinder of synthetic sapphire or high purity silica previously metalized.

These frequencies correspond to acoustic wavelengths in the micrometer range, given the speed of ultrasound waves, which is of the order of several thousand meters per second. The maximum spatial resolution achieved, due to the limitation by diffraction, is about a fraction of a wavelength. The resolution is obtained by interposing between the ultrasound source and the object, an acoustic lens focusing. Such diopter is achieved using two materials for which, the ratio of acoustic velocities approaches the ten. Thus, the sapphire is the first medium (the fastest) and includes, on the flat opposite face to the transducer, a small spherical diopter etched and well polished. The diameter is about one hundred microns for an acoustic frequency of 1 GHz and a few millimeters for frequencies between 10 MHz and 100 MHz. The second medium will be liquid, usually water, to ensure acoustic coupling with the object and allows it to vibrate.

The ultrasound beam is focused into a very small spot, located in the plane of the object. You can take an image of the object by reflection or transmission respectively by collecting the reflected beams or the transmitted beam.

On transmission / reflection mode, the transmitter system is also a receiver using the inverse piezoelectric effect: the emitted and reflected signals are then separated in time in the same way as radar. In transmission mode, a second sensor is put symmetrically to the first.

The acoustic image of the object in a parallel plane to its surface is obtained by a mechanical scanning of the sample, relative to the sensor (or vice versa) along two perpendicular directions X, Y in the focal plane of the lens. Information received by the transducers is amplified, filtered, digitized and stored in a memory in correspondence with the movements of the object. A digital signal processing achieves a time separation of echoes and computes its power to have at the end a single number. The final image is coded in false colors to be displayed on a conventional monitor as a standard image. The magnification achieved, is comparable to those obtained in optics, ranging from a ten to about 2000. The maximum field observed varies according to the possibilities of mechanical scanning system and the settings of the instrument. It varies from a fraction of square millimeter to several square decimeters for an image acquisition time of one to several minutes depending on the requested resolutions.

2.2 Improvement of data acquisition

To observe multi layer samples as power modules, we used a scanning acoustic microscope with a spherical acoustic lens to focus the acoustic beam. The acoustic image is made from the transmission and reception of ultrasonic waves. Each pixel of the image located in an XY plane is function of the acoustic energy reflected. Moving mechanical linear stages, with a precision of the order of 100 nanometers, performs scanning. The contrast depends of the localized variations in structure or mechanical properties [2]. The acoustic images are obtained after scanning in the XY plane for a constant distance in Z. Therefore, according to the distance Z, the images can be obtained either on surface or in depth. In this work we used the reflection mode in a systematic way to obtain an acoustic signal.

This new acquisition method [3] includes the following specific steps, added to those of traditional acoustic microscope already described previously.

- A software was developed to help technician to focus the acoustic waves at the interface to be examined. The absolute position of the sensor for this focus point is obtained by theoretical simulation of wave propagation thru acoustical lens until the interface of the multi layer material to be examined. The input data considered for this simulation are acoustic velocity of the coupling fluid, acoustic velocities and thicknesses of each layer. This software enables optimum focus without the obligation to identify the interface echo, sometimes buried in the noise.

- A direct sampling of the ultrasonic signal is made up of sampling frequencies, up 8 Giga samples per second with 8 or 10 bits resolution in function of the device.

2.3 Improvement of data processing

To reject a maximum of noise we use a vectorial treatment. In burst mode, with the sampled signal and the reference acquired separately, the amplitude and the phase of the signal are computed for all windows timing. In pulse mode, a reference signal is first synthesised. Figure 2 presents the raw sampled signal with amplitude and phase. We can notice on the part where there is no acoustical echo, the amplitude is very low and the phase is noisy.

Using these curves (amplitude and phase) we first calculate the amplitude and the phase of the echo. Many methods are possible, such as to extract the maximum of the amplitude and read the phase at the same acquisition time. Another method is to plot in the complex graph or the phasor diagram all the vectors from amplitude and phase curves.

Each vector is calculated from sampled points. The additions of these vectors give a mean vector representative of the amplitude and the phase of the average echo. This method is very interesting: adding up non-coherent signals (generally white or pink noise) it gives a vector very close to the null vector.

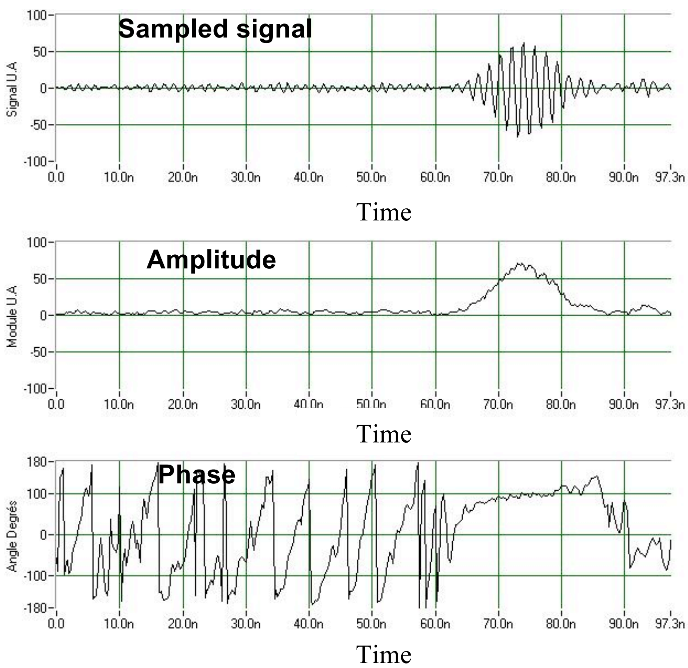

Figure 2: Raw sampled signal (top), computed amplitude (centre) and phase (bottom) of an acoustical echo obtained in reflection mode.

The noise is filtered in the same way of a synchronous detection. The figure 3 presents the phasor diagram of the curves of the figure 2. The non-coherent noise is concentrated near the origin, removed by the vector sum of the signal since its phase is random. This last step requires the prior determination module / phase of each sample acquired and a time selection of the interesting acoustic signal. Optionally, the determination by calculus of the frequency spectrum in modulus and phase of the signal can be integrated into the protocol to compute the energy of the reflected echoes in function of the frequency.

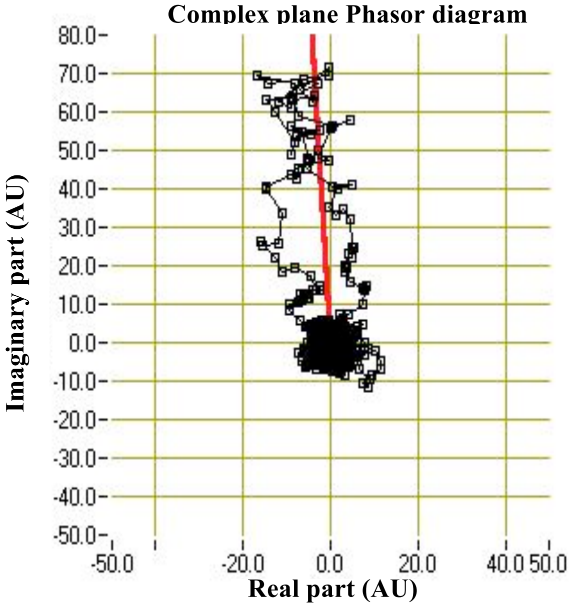

Figure 3: Phasor diagram or complex plane. Data from the figure 2

Often, surfaces and interfaces of studied material are not parallel each other. It makes images difficult to interpret when we examine the interface because of the shift in time of the echoes. To compensate thickness inhomogeneity of layer (manufacturing defects of the coating, curvature imposed or linked to achieving...), a signal processing for echoes time warping, using intercorrelations methods is done. This treatment allows a fit of the topography, especially when layers have a non-constant thicknesses (figure 4).

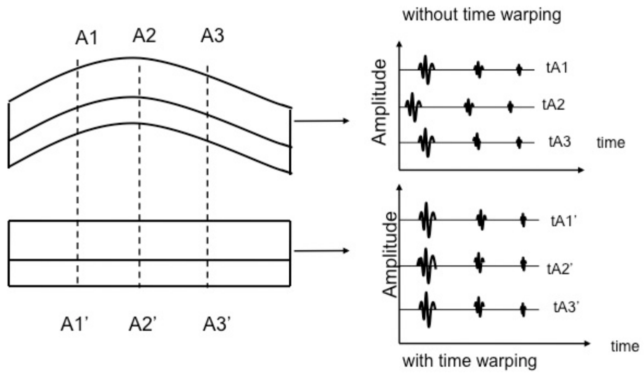

Figure 4 : Compensation for inhomogeneity of flatness of the layer by time warping

The choice of echo containing information (figure 5) is accomplished by echoes time selection, with or without using time warping described above.

Figure 5 : Echoes time selection

3 Results and analysis

We will present results from a sample shown in figure 6. This is a electronic power module containing IGBTs and diodes.

The major difficulty is, at frequencies around 50 MHz or more, to separate the different interfaces and make a 3D reconstruction with a correct image quality of interfaces away from the surface.

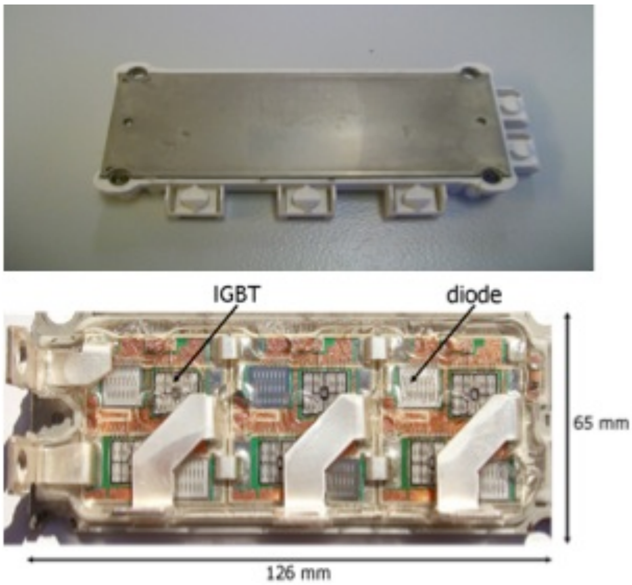

Figure 6 : Test sample : electronic power module

A simple acoustic image is not an option. The curvature of the sample does not produce correct images of subsurface. The figure 7 shows the surface topography of the sample.

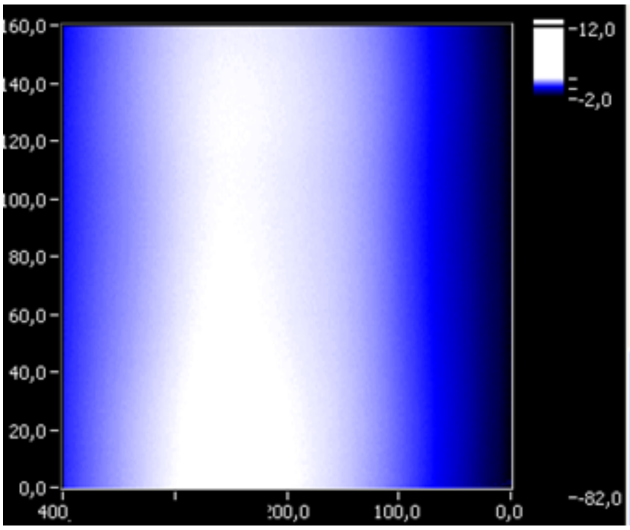

Figure 7 : Image of the surface topography of the sample.

When applying the time warping, there is an alignment of all echoes interfaces. The figures 8 and 9 show a B scan image before and after time warping.

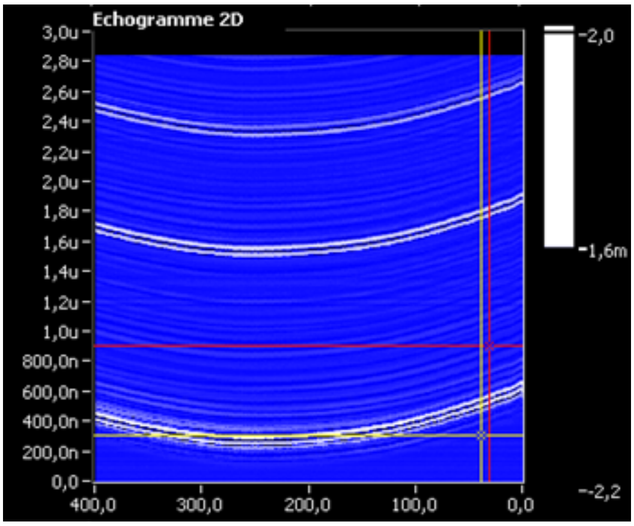

Figure 8 : B-scan image before time warping.

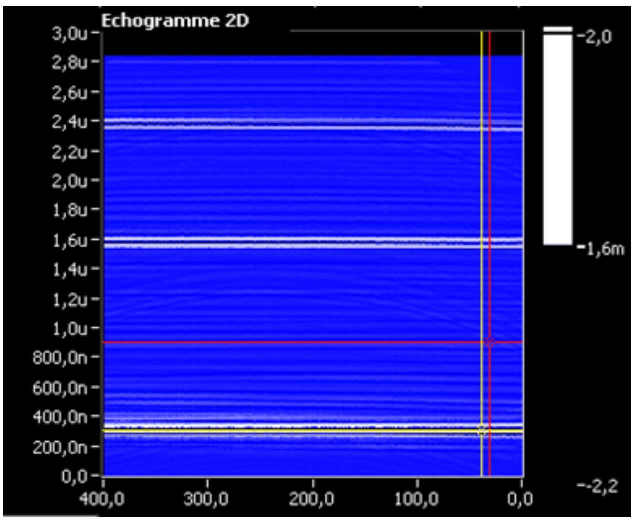

Figure 9 : B-scan image after time warping.

An application of this method of time warping, then a selection of different echoes, allow obtaining acoustic images of all interfaces. The figure 10 shows a schematic section of the component and acoustics images of interfaces. These images highlight the possibility of imaging by high-frequency acoustic microscopy interfaces of a multi layer sample non planar.

The setting of a large number of images, one after another can make a film reproducing a 3D vision

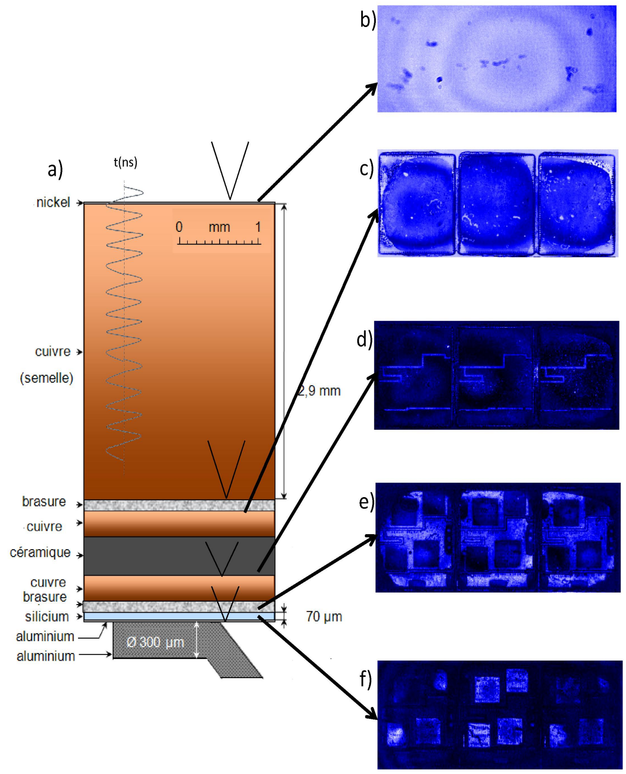

Figure 10 : Schematic section of the component and acoustics images of interfaces.

4 Conclusion

This method of acquisition and the signal processing associated, combined with traditional focused high frequency scanning acoustic microscopy, enable high resolution imaging of defects in buried layers through very thick substrates.

Thus, we now have a non-destructive imaging tool for assessing the physical properties of complex multi layer structures of power electronics devices.

The presentation of results is ensured by a signal processing of acoustic echoes to make films of buried interfaces in function of the depth inside the sample, using time signal. This signal processing allows to reconstruct the image of the object within the depth of field of the acoustic lens with only one image acquisition but a wide time window.

Acknowledgments

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