Application of the ultrasonic pulse-echo technique for quality control of the multi-layered electronic components

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Abstract:

The objective of the presented work was enhancement of quality of ultrasonic images of electronic components, obtained by the pulse-echo ultrasonic technique. For this purpose a novel signal processing method based on the adaptive ultrasonic numerical model of the electronic device and selection of the appropriate time and frequency regions has been proposed.

Key words: quality control, electronic component, delamination defect, signal processing.

Introduction

In the production of microelectronic devices, the electronic component encapsulation process has a predominant role. In fact, the amount of defects in such components depends mainly on this phase of manufacturing and also on surface mounting processes. The defects can be localized at the interface between the different layers (delaminations, cracks, voids, metal corrosion) or in the silicon die affecting both the electrical behavior and the thermal dissipation. Mismatch of expansion coefficients between the elements of a micro assembly, die backside or solder oxidation, intermetallic phases, or fast cooling conditions during the reflow process can induce stresses following die bonding. The exceeding of a determined level of defectiveness requirements involves a low reliability or malfunction of the devices. Therefore it is necessary to determine the number, spatial distribution, dimensions and the depth of the defects in the structure under a quality control test. Different NDT techniques such as visual inspection, radiography, thermography and ultrasonic technique are exploited for detection of defects in printed circuit boards and in the internal structure of electronic components. The consequence is a rejection of components where the defects exceed the allowed maximum and eventually of modifying parameters of the manufacturing process to improve reliability [1-4].

The ultrasonic technique is attractive for NDT application due to one side access: also it enables to detect very thin internal delaminations in printed circuit boards (PCB) and multi-layered electronic components, detection of which is more problematic by other techniques. Due to requirements of a very high spatial resolution of the defect imaging, the conventional ultrasonic methods need essential improvement. To improve detection and characterization of internal defects inside electronic components, various testing methods and signal processing procedures have been used, including phase imaging, the Wiener filtering, the wavelet transform, deconvolution and etc. [1-6].

The objective of the presented work was to investigate accuracy of detection of different types of defects and to select parameters of the acoustic inspection system and the method of signal processing, which enables to enhance quality of ultrasonic images.

Investigation of a high voltage semiconductor device

For on-line investigation of a high voltage semiconductor components, the combination of the pulse-echo and the through-transmission ultrasonic techniques has been exploited. The immersion experimental set-up used for this purpose is presented in Fig.1. The focussed ultrasonic transducer with the central frequency 10 MHz, the diameter 6 mm and the focal distance 50 mm was used for investigation. Mechanical positioning of the transducer and data acquisition were performed using the ultrasonic measurement system developed at the Ultrasound Institute of Kaunas University of Technology. During the alignment of the transducer to the sample surface, it was assumed that the maximum amplitude corresponds to the normal incidence angle to the surface of the sample. The multi-layered electronic component under investigation consists of molybdenum layer, Al-Si gasket layer, Si layer, gold electrode layer (Fig.1). The mechanical and acoustic properties of each layer were known in advance. The scanning of the ultrasonic transducer has been performed in the region with dimensions 40 mm along *x* axis and 50 mm along *y* axis. The scanning step was the 1 mm. The numerical model of the multi-layered structure under investigation was developed and simulation of the expected waveform, reflected by the whole structure of the electronic component, was performed. The six reflections from the adjacent interfaces have been analysed: R_1 is reflection from the interface between water and the molybdenum layer, R_2 is reflection from the interface between the molybdenum layer and the Al-Si gasket, R_3 is the reflection from the interface between the Al-Si gasket and the Si layer, R_4 is the reflection from the interface between the Si layer and the gold electrode, R_5 is the reflection from the interface between the gold electrode and water, R_6 is the reflection from the interface between water and the flat Plexiglas reflector, which is used to mimic the through-transmission mode of the ultrasonic wave propagation through the whole structure of the electronic component.

The experimental and the simulated A-scan signals obtained from different regions of the electronic component are presented in Fig.2 and 3. The multiple reflections from adjacent layers have been also taken into account, however the appropriate spikes of the spatial pulse response have been not presented in the graphs. These results indicate small deviations of the reflection amplitudes, however it is possible to obtain the symptoms of the internal structure anomalies and non-homogeneities, which are caused by internal delaminations or by presence of the gold electrode.

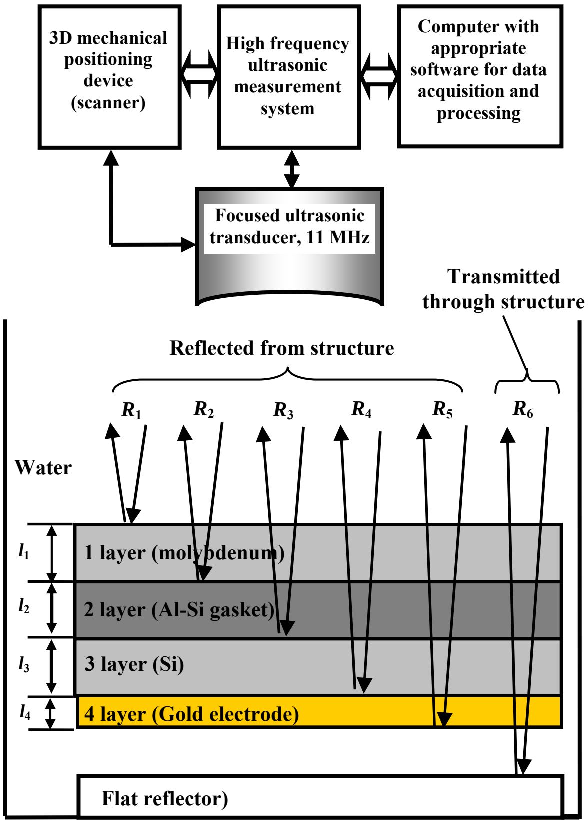


Fig.1. **Experimental set-up for on-line immersion testing of electronic components based on combination of the pulse-echo and through-transmission techniques, having only one-side access to the object: R_1 is the reflection from the interface between water and the molybdenum layer, R_2 is the reflection from the interface between the molybdenum layer and the Al-Si gasket, R_3 is the reflection from the interface between the Al-Si gasket and the Si layer, R_4 is the reflection from the interface between the Si layer and the gold electrode, R_5 is the reflection from the interface between the gold electrode and water, R_6 is the reflection from the interface between water and the flat Plexiglas reflector**.

The simulated waveforms of the ultrasonic signals, which have been transmitted twice (direct transmission through the semiconductor component, reflection from the additional flat reflector and transmission again through the component back to the transducer) through the different regions of the electronic component are presented in Fig.5. These results indicate the “shadowing” effect of the delamination in the case of the ultrasonic wave propagating backward from Plexiglas reflector to the ultrasonic transducer. Such effect reduces amplitude of the appropriate segment of received signal and can be observed in the experimentally measured signals transmitted through electronic component also (Fig.3 and Fig.4).

The C –scan images can be created using the reflected or through transmitted signals in which informative segments are selected by the time window (Fig.2, 3 and 4). The better spatial resolution may be obtained subtracting images obtained from the reflected (Fig.6 a) and the through transmitted signals (Fig.6 b). The image obtained in such a way is presented in Fig.6 c. The internal delamination defects between the molybdenum and the Al-Si gasket layers and also the presence of the gold electrode can be observed.

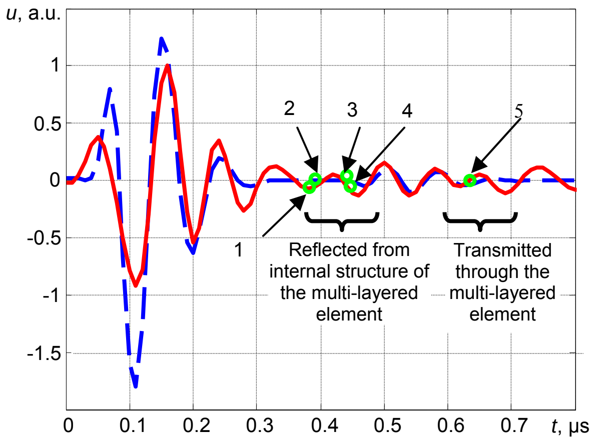


Fig.2. **The experimental (solid line) and the simulated (dashed line) A-scan signals obtained from the region in which the gold electrode is present. The expected arrival times and amplitudes of the appropriate reflections are denoted by solid circles: 1 – the reflection from the interface between the molybdenum layer and the Al-Si gasket, 2 - the reflection from the interface between the Al-Si gasket and the Si layer, 3, 4 – the reflection from the gold electrode layer, 5 – the reflection from the interface between water and the flat reflector.**

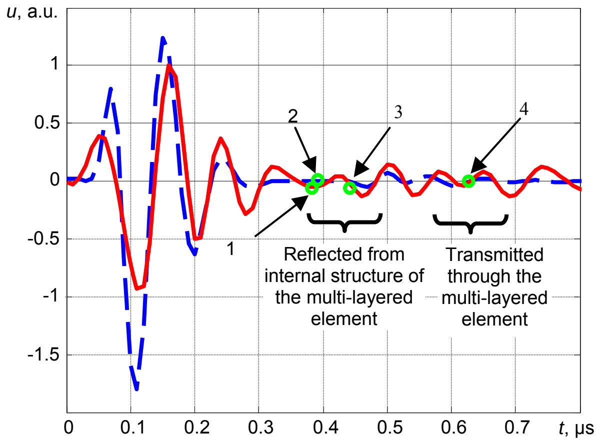


Fig.3. **The experimental (solid line) and the simulated (dashed line) A-scan signals obtained from the region in which the gold electrode is absent. The expected arrival times and amplitudes of the appropriate reflections are denoted by solid circles: 1 – the reflection from the interface between the molybdenum layer and the Al-Si gasket, 2 - the reflection from the interface between the Al-Si gasket and the Si layer, 3 – the reflection from the interface between the Si layer and water, 4 - the reflection from the interface between water and the flat reflector.**

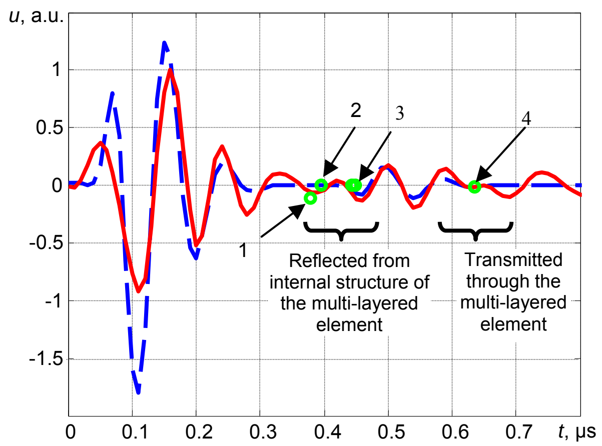


Fig.4. **The experimental (solid line) and the simulated (dashed line) A-scan signals obtained from the region of delamination between the molybdenum layer and the Al-Si gasket. The expected arrival times and amplitudes of the appropriate reflections are presented by solid circles: 1 - the reflection from the delamination, 2 - the reflection from the interface between the Al-Si gasket and the Si layer (the reflection is completely suppressed), 3 - the reflection from the gold electrode (the reflection is completely suppressed), 4 - the reflection from the interface between water and the flat reflector (the reflection is completely suppressed).**

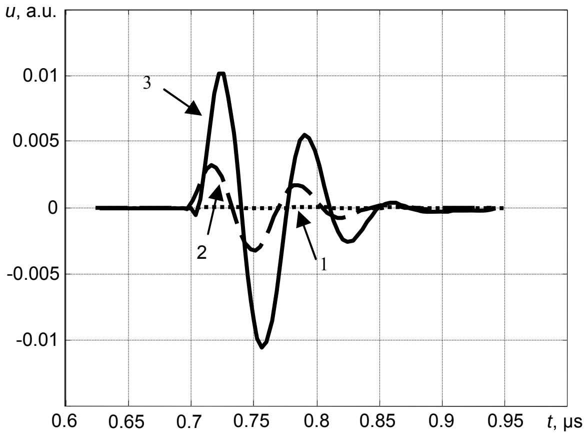
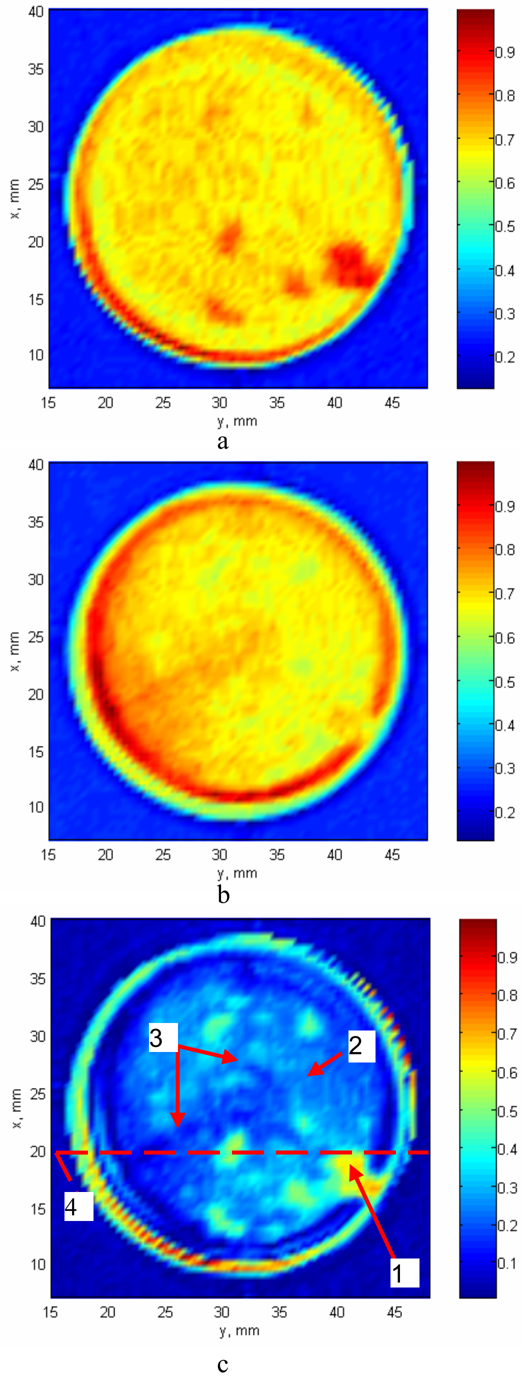


Fig.5. **Waveforms of the simulated ultrasonic signals in the through-transmission mode, which have been transmitted twice and has been obtained in direct transmission through the electronic component, reflection from the additional flat reflector and transmission again through the component back to the transducer (in three different zones of the electronic component): 1 – delamination between the molybdenum layer and the Al-Si gasket, 2 – the gold electrode is present, 3 - the gold electrode is absent.**



a

b

c

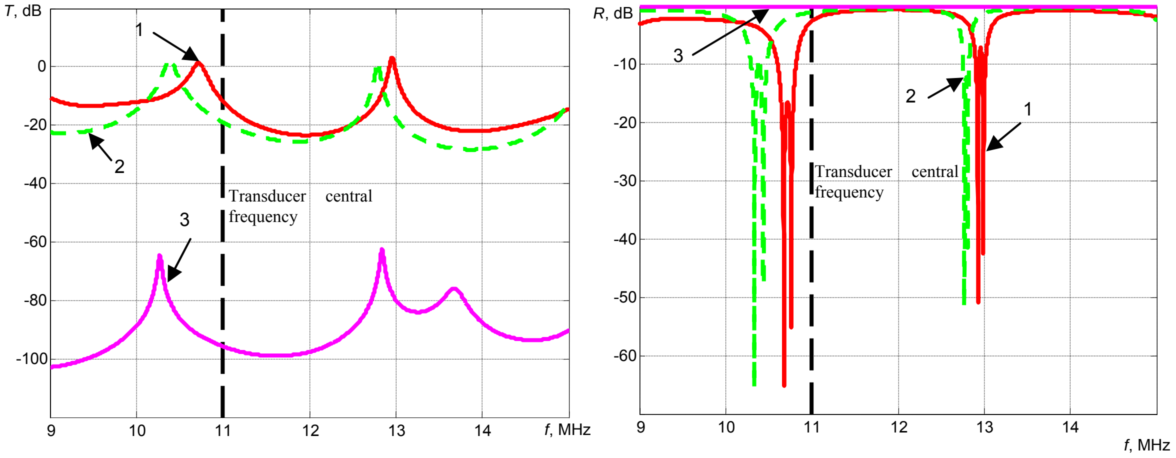
Fig.6. **The C-scan image of the electronic component obtained by combination (c) of the pulse-echo (a) and through transmission (b) modes: 1 – delamination region at the interface between the molybdenum layer and the Al-Si gasket, 2 –the region without defects in which the gold electrode is present, 3 - the region without defects in which the gold electrode is absent, 4 - the cross-section of the C-scan selected for data evaluation in the frequency domain.**

Processing in the frequency domain

For a more detailed analysis the reflection and the transfer functions have been calculated using one dimensional approach [5]-[6]. The transfer functions of the plane wave propagating through the whole structure of the electronic component are presented in Fig.7 a. It can be seen that the presence of the additional thin gold layer shifts the maximum of the transfer function to the lower frequencies. The delamination changes the transfer function in a similar way, but additionally much higher losses are introduced due to the almost complete reflection of the ultrasonic wave. The dependencies of the reflection functions for the same cases are presented in Fig.7 b. It can be observed that in the case of the defect when the complete reflection occurs the character of the reflection function is not affected. Due to this, the spatial distribution of the spectra magnitude of the signals reflected by the various interfaces of the semiconductor device along the line 4 in Fig.6, crossing the delaminated area, does not give any additional information about defective zones.

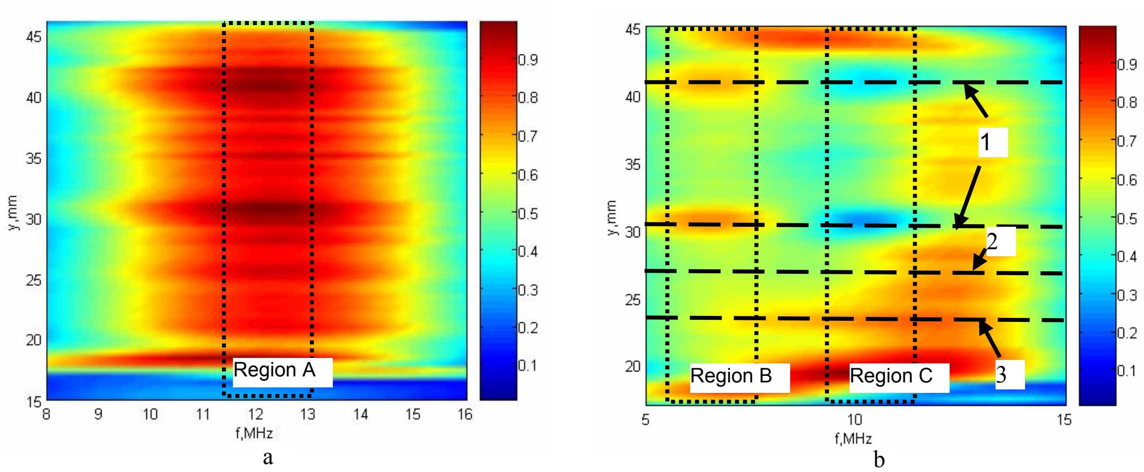
However, the spectra magnitudes of the reflected and through transmitted segments of the received signals possess more information and are presented in Fig.8. The region A, region B and region C (Fig.8 a,b) indicate the presence of delamination type defects which cause appropriate frequency shifts. In order to increase the contrast of the C-scan the differential type (difference between regions A, B and C) spectra magnitude C-scan image has been created. The differential C-scan image of the electronic component obtained by combination of the three regions of the spectra magnitude, created from the reflected (Fig.9 a) and through transmitted (Fig.9 b) parts of the received signal is presented in Fig.9 c.

The differential C-scan image of the defect free electronic component obtained by combination of the three regions of the spectra magnitude, obtained in reflection and through transmission modes is presented in Fig.10. The presented results clearly indicate the enhancement of the defect contrast and boundaries, which enables better localization and detection of the internal defects.



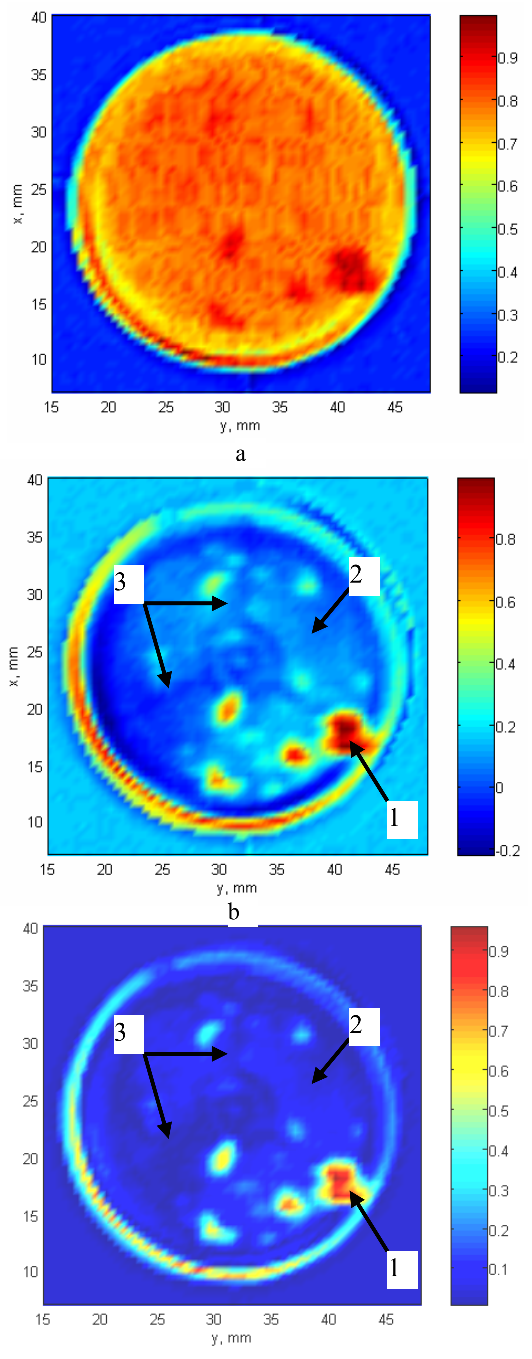
a b

Fig.7. **Transfer (a) and reflection (b) functions of a plane ultrasonic wave propagating through the semiconductor device: 1 – the region without defects in which the gold electrode is absent, 2 – the region without defects in which the gold electrode is present, 3 – the region with a delamination at the interface between the molybdenum layer and the Al-Si gasket**.



a b

Fig.8**. Spatial distribution of the spectra magnitudes along the selected cross-section (Fig.6 the dashed line 4), which corresponds to the reflected part of the received signal waveform (a) and to through-transmitted part of the received signal waveform (b): 1 – the region with delamination at the interface between the molybdenum layer and the Al-Si gasket, 2 – the region without defects in which the gold electrode is present, 3 - the region without defects in which the gold electrode is absent**.



a

b

c

Fig.9. **The differential C-scan image (c) of the electronic component obtained by combination of the three regions of the spectra magnitude, obtained in the reflection (a) and the through transmission (b) modes: 1 – the region with delamination at the interface between the molybdenum layer and the Al-Si gasket, 2 – the region without defects in which the gold electrode is present, 3 - the region without defects in which the gold electrode is absent.**

Conclusion

The investigation results of the high voltage semiconductor component by ultrasonic technique were presented. In order to improve the spatial resolution of a conventional C-scan image, the signal processing technique based on the selection of the signal components in the time and frequency domains has been proposed. This technique is based on the adaptive ultrasonic numerical model of the electronic device, which enables to optimize the selection of ultrasonic signal segments possessing the information about internal defects. Such selection has been applied for the appropriate parts (reflected and transmitted) in the reflected signal waveform in the time and in the frequency domains. The results presented prove that this approach enables to get improved contrast and resolution of internal delamination type defects of the multi-layered electronic components. Hence, the proposed approach gives additional information for spatial localisation of the internal defects during quality control.

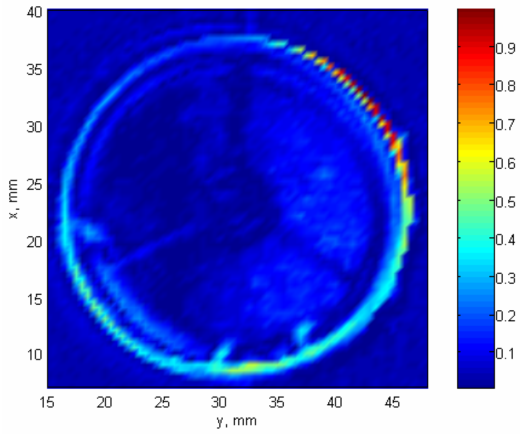


Fig.10. **The differential C-scan image of the defect free electronic component obtained by combination of the three regions of the spectra magnitude, obtained in reflection and through transmission modes.**

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Ultragarsinių metodų taikymas elektroninių komponentų struktūros vidinių defektų parametrams matuoti

Reziumė

Elektroninių komponentų kokybės kontrolė gamybos proceso metu, atliekama įvairiais NDT metodais, vizualiniais, rentgeno, termografiniais, ultragarsiniais. Kontrolės metu siekiama nustatyti įvairių tipų defektus,

kurių įvairovė bendruoju atveju yra labai plati. Vieni iš svarbiausių defektų yra atskirų sluoksnių, sudarančių elektroninius komponentus, atplyšimas. Jie daugiausia sąlygoti temperatūros poveikio gamybinio ciklo metu. Tokie defektai lengviausiai aptinkami ultragarsiniais metodais. Tačiau taikant šiuos metodus daug tyrimo laiko sugaištama preciziškai skenuojant fokusuotą ultragarsinį keitiklį virš tiriamojo objekto paviršiaus, kuris priklauso nuo tiriamo komponento integracijos laipsnio. Be to, siekiant didelio erdvinio skiriamumo reikia naudoti aukštojo dažnio ultragarso bangas (50–100 MHz). Taigi ultragarsiniai metodai daugiausia naudojami tyrimams laboratorinėmis sąlygomis atlikti ir sunkiai pritaikomi kokybės kontrolei gamyboje. Ultragarsinio keitiklio skenavimo greičio padidinimas arba ultragarso bangų dažnio sumažinimas pablogina tyrimo rezultatų kokybę. Pateikto darbo tikslas buvo padidinti ultragarsinio keitiklio skenavimo greitį ir sumažinti darbo dažnį, kartu išlaikant pakankamą vidinių defektų geometrinių matmenų matavimo tikslumą.

Buvo pasiūlyta taikyti specializuotus signalų apdorojimo algoritmus ir kombinuotą matavimo metodiką, įvertinančią nuo vidinės komponento struktūros atsispindėjusias ir tiesiogiai perėjusias ultragarso bangas. Kad būtų nustatomi tikslesni vidinių atsisluoksniavimo defektų geometriniai matmenys, pasiūlyta naudoti laikinį ir dažninį informatyvių ultragarsinio signalo segmentų išrinkimą, pagrįstą skaitmeniniais ultragarso bangų sąveikos su tiriamojo komponento vidine struktūra modeliais. Naudojant skaitmeninius modelius buvo apskaičiuotos tiriamo daugiasluoksnio elektroninio komponento dažninės charakteristikos ultragarso bangų atspindžio ir perėjimo atvejais, taip pat nustatytos tikėtinos nuo atskirų sluoksnių atspindėtų signalų laikinės padėtys. Atspindžiams aptikti buvo matuojami signalai, atspindėti nuo komponento vidinės struktūros, ir signalai, perėję per komponento vidinę struktūrą ir atsispindėję nuo papildomo reflektoriaus. Pasiūlytoji matavimo metodika sujungia rezultatus, gautus analizuojant abiejų tipų signalus.

Sukurto metodo veiksmingumą rodo keturių sluoksnių puslaidininkinių didelės galios diodų tyrimo rezultatai. Čia aiškiai matomos atsisluoksniavimo sritys.

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