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# A review on echo and phase inverted scanning in acoustic microscopy for failure analysis

***Abstract**. This paper is a review on the part of the failure analysis in the semiconductor region, especially in the integrated circuit (IC) design. Initially, the literature review depends on the keyword of acoustic-microscopy. Then, it followed by the example on the scanning acoustic-microscope (SAM), confocal scanning acoustic-microscope (CSAM), and C-mode scanning acoustic-microscope (C-SAM) technique. These three SAM techniques are used in various situation and have a different effect on the sample. Previous works on SAM, C-SAM and CSAM related technologies are reviewed by many researchers in this paper.*

***Streszczenie** W artykule przedstawiono przegląd analizy defektów układów półprzewodnikowych (obwodów scalonych) z wykorzystaniem mikroskopów akustycznych. Zaprezentowano mikroskop akustyczny SAM, mikroskop skaningowy CSAM i mikroskop typu C C-SAM. Każda z tych metod pozwala na różnego typu badania **(Przegląd metod wykorzystania mikroskopów akustycznych do analizy uszodzeń układów półprzewodnikowych)***

**Keywords**: Acoustic microscopy, C-mode scanning acoustic-microscope (C-SAM), Confocal scanning acoustic-microscope (CSAM), Scanning acoustic-microscope (SAM).
**Słowa kluczowe:** mikorskop akustyczny, mikroskop skaningowy, mikroskop SAM, CSAM I CSAM

## Introduction

Today's electronic systems are becoming more complex and compact, FC is the inevitable component of IC in the semiconductor production topic. In fabricating development work, this failure analysis subject is related and concerning numerous failure situations condition. In manufacturing quality control of microelectronic components, non-destructive failure analysis approaches are trustworthy practices and precarious in quality control work. This FC possibility that comprehends electrical properties, the extreme performance of physical and chemical procedure with the analysis of the mechanisms to describe the Method to resolve the problems of quality and dependability enhancement in manufacturing or application field area that expected of the customer wanted [1-3].

An acoustic wave is a corporeal phenomenon accountable for the transmission of dilatational and shears straining. Basically, the imaging technology can be manipulating the optical waves to get the data. But it shows that this optics cannot deliver many data and information. So, to cater this problem, the alternative solutions had been used and acoustical imaging is chosen wisely. An acoustic microscopy is an efficient tool for the quantitative characterization and it's successfully applied in several areas such as biology, industrial technology, and physics and also in the semiconductor industries. Several areas that apply this acoustic microscope are FC, process control, reliability, vendor qualification, quality control, production and in the research work in the laboratory and universities [4].

This acoustic microscopy technique demonstrates improvements and actions of science and technology that permits for the growth of research, generates occasions for finding, authorizations unfathomable investigation of a specimen and allows researcher to better analyse and observe micro-environments with more accurate specimen data.

In the area of contamination outlook, micro and nano-size particles can consume main influence on the act of accuracy and further outcomes in a wide range of applications in several manufacturing processes. In the semiconductor area, the serious necessity is to characterize particles, this is because beyond years, it shows that the reduce of size features in the nanometer range.

Stated in history in 1936 by Sokolov, his had been projected a device for creating amplified sights of structure with 3GHz sound-waves. Though, due of lack technology and equipment, the first constructed work of acoustic microscopy experiments only done in by Dunn and Fry in 1959 [5].

Nowadays, acoustic microscopes are interesting topic that widely used for last two decades in different purposes [6]. This acoustic microscope controls the nondestructively and enter furthermost solid materials to create the observable images of internal features, counting faults like voids condition, cracks problems, and delamination's structure. The acoustic microscopy basically works on an ultra-high frequency (UHF) ultrasound and also very high frequency (VHF).

For examples, this subject had been used in several functions for measuring attenuation of surface waves and velocity in the material in an effort to acquire the flexible characteristics of the material, focused by [7]in his paper. Besides that, the same author review that it's also functioning to extent the anisotropy in a material [8].

If review backs the previous work on this subject, majority stated that the theoretical and experimental investigations on acoustic microscopy are focused at the same frequency range nearly 100 MHz. The reason of this matter is the microscope resolution is high, basically shows in high frequency. But this disadvantage founded in this situation is the poor effect of the signal penetration property. [9] had been exploring to use low frequency range nearly below 10 MHz in his experiment and its shows more efficiently in the arenas of mechanical engineering and materials science.

There are at least three different simple kinds of acoustic-microscope, namely as C-SAM, CSAM and SAM [10]. The SAM is a device that practices to intensive sound to examine, portion, or image an entity (scanning acoustic tomography). These three different types are applied in the failure analysis works and for non-destructive evaluation. Basically, the current used in in the research is C-SAM type instruments. Other work on the acoustic microscopy can be found in this several previous works by Chertov 2007 [11], Jakob 2009 [12], Mamou 2017 [13], and Meignen 2017 [14].

In paper is stated on the FA on echo and phase scanning in acoustic microscopy for failure analysis.

Several techniques had been discussed in this paper, namely SAM, CSAM, and C-SAM.

**Scanning acoustic microscope**

The high resolution acoustic imaging technology that using the SAM is started in the mid-1970's [15]. Fig. 1 is shows the Tessonics acoustical microscope. This equipment can be used for nondestructive material assessment and laboratory research work of the internal structure for both biomedical and industrial samples.

Resistance spot welding is a common method of joining two or more sheets of metal; it is both fast and easily automated. The process is as follows: two (or more) sheets are squeezed between two electrodes with a force ranging from 500 to 1500 lbs. Electrical current (5-15 kA) is then sent through the stack-up for a short period of time (~100-500 ms). The inherent resistance of metal-metal interfaces, as well as the bulk metal, generates heat that is able to melt a certain volume of metal between the lower resistance copper electrodes. On solidification, the liquid metal volume, having subsequently penetrated into both plates, forms a joint permanently securing the sheets together as shown in Fig (2) [16].

Fig. 1: Tessonics acoustical microscope

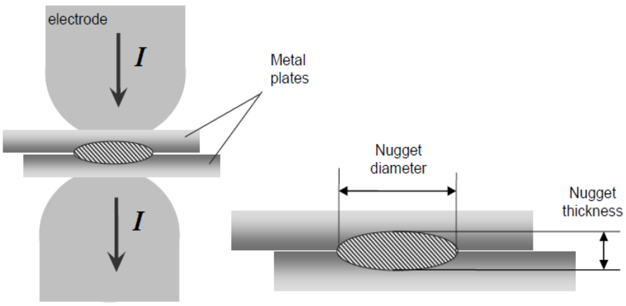
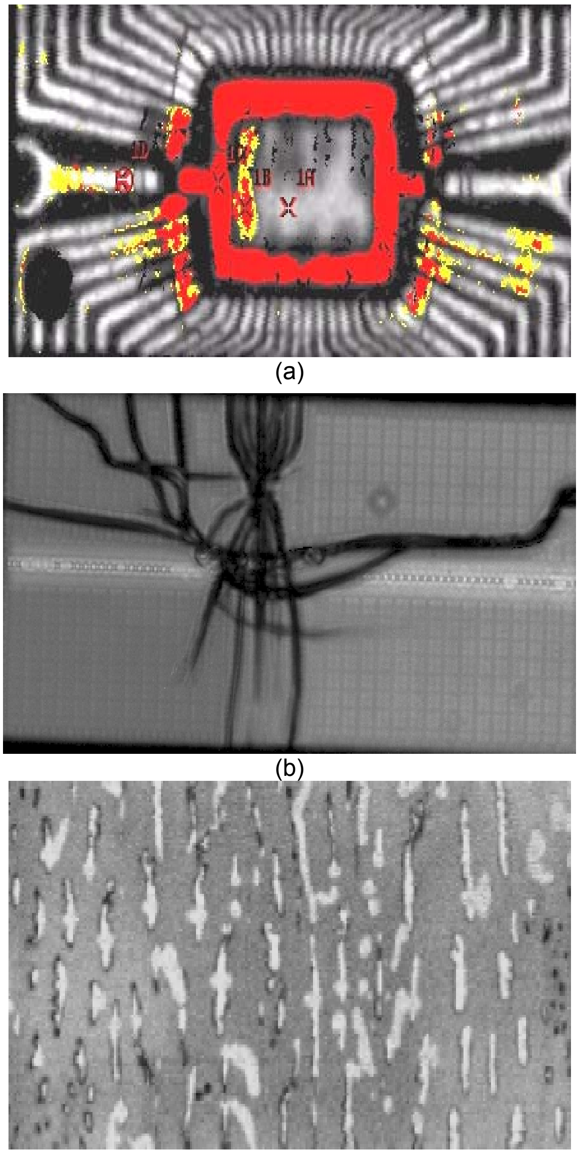



Fig. 2: Resistance welding process and weld structure [16]

The first ever SAM are design using the principles of continuous wave ultrasonics, stated in Lemon's paper in 1974. He is applying this technique by using single-surface lenses with 10 μm resolution and with sensitivities of 10−8 W/cm2 [17].

SAM is probably important in the failure analysis, as it avoids firms and factory from industries from delivery bad goods and protects to use an expensive cost of production. SAM hardware actually is the associations the mechanical scanning arrangement with an ultrasonic emitting receiving system. It is using high frequency ultrasonic waves and influential technology for the imaging of the interior structure of materials of a diverse nature.

The result data from the acoustic image can be applying to analyse structures such as cracks, encapsulates cracking, check ceramic direct bond for delamination's, air gaps and pre-existing voids/internal mold void [18] with relative ease and sustain sample quality of hermetically sealed items. It also has a capacity to preference up on sub-micron features that typical x-ray cannot detect like popcorn cracking and die attach voiding. Fig. 3 shows the example in analysing data.



(a)

(b)

(c)

Fig. 3: Example of analysing data, (a) delamination. (b) Die crack, (c) lid seal voids[17]

Since SAM can view internal structures, it has the. By this SAM technique, the researcher can be applying to analyses the samples deprived of discoloration it or initiating it any damage which trusts on a beam to scan and enter the specimen whereas it is in water.

This SAM is the nondestructive technique that used to sense the fluctuations in elastic properties of solids. It also figures that; it can plot and count microstructure of material as differences in acoustic impedance. Different from X-ray topography features, this SAM technique is comparatively low-priced and is related to both amorphous and crystalline materials [18]. Equated to the extensively and used non-destructive technique and medical ultrasound, this SAM functions with higher frequencies and at relatively short distances.

The main part of the SAM is the acoustic lens that contain by the sapphire rod with a spherical cavity engrossed in an unsolidified that interactions the specimen under observation. In this case, a piezoelectric transducer creates pounded ultrasonic waves in the frequencies between 10MHz and 2GHz, which promulgate as acoustic plane waves laterally the lens rod.

In [19], he is using the SAM technique to imaging system calculates and color codes speed of sound (SOS) per square area in samples of chosen tissue regions. This SAM basically can offer tissue elasticity imaging and prosper in specific histological imaging of normal lymph nodes. Besides that, it also delivers the localized images of lymph follicles, and granulomatous inflammation, neoplastic lesions, germinal centers, cords and medullary sinuses, fibrous capsules, paracortex, adipose tissues, necrosis, granulomas, metastatic carcinoma and fibrosis. In his other paper, Beside SOS and AOS, this SAM might be functioning to measure the cell size, borders, contents, cell connections and structures, like LM.

Besides advantage of the SAM, it also has several limitations such as it is avoiding it from fetching a prevalent field once it derives to research study and investigation, especially in the microelectronics industry. The other work on SAM also can founded in several works, example in Oberhoff, 2012 [20] and Lee, 2003 [21]

**Confocal scanning acoustic microscope**

Another type of SAM is CSAM. Confocal microscopy is a method in optical imaging is has a procedures of point illumination via a spatial pinhole to abolish out of focus signal [22] This CSAM is non-destructive (NDT) investigation setup for sensing and imaging microscopic constructions of spots intimate a specimen. It is extensively and broadly practices in semiconductors and electronics works by practice of the reflection and transmission properties of ultrasonic waves. The CSAM tools has unresolved profit is its capability to discovery the unseen defects (such as delamination's, fine crack, voids and porosity) within an assembly that can happen throughout the manufacturing or rehabilitee testing.

**C-mode scanning acoustic microscope**

C-SAM is another type of SAM technique that had been applies by previous researcher. Same as the SAM before, the C-SAM test it's based on the type of parts that used. This method can be used for ultrasonic inspection of die-attach, unbonded regions, delamination's and/or voids in the die-attach material.

Below are shown the several works on that apply the C-SAM. Firstly, Koskinen in 2012 [23] is using C-SAM in his paper to describe the indications of the dissimilar kinds of artificial defects that apply for qualification of NDT methods. The scrutiny element is the austenitic stainless-steel pipe with thermal fatigue cracks and similar size of EDM slits. In this case, the SAM setup works by leading absorbed sound from a transducer towards a direct location to the sample under test. The sample is wrapped up in liquid while the probe is glancing over an area of need. As a conclusion, it shows that the CSAM had been checked using EDM slits and comparable size of thermal fatigue cracks. Fig. 4 shows C-SAM set up by the Ultrasonic Sciences Ltd and the examples of the surface microscopy image. The setup is arranged firstly at the left by the immersion tank and the manipulator system, at the center with the ultrasonic equipment and at the right is located the main computer.

Another work by Mugunan [24]is describe and compare on the different non-destructive method using C-SAM bottom scan to authenticate the delamination spotted by the Transmission Mode (Thru-Scan) by progressively scanning from the bottom of the package. Fig. 5 shows the differential between Reflection Mode and Transmission Mode. It shows that the several comparisons between the Reflection Mode of C-SAM it can identified the specific location interface, but the Transmission Mode cannot regulate where the affected interface location. Besides that, it also that the C-SAM shows the clarity and details in mage with enhanced spatial resolution compare with other technique is only appear the fuzzy image because of unfortunate spatial resolution. The last comparison can be made by the delamination effect. It shows that the C-SAM method can be able to expose the irregularities besides delamination which is cannot be detected by Thru-Scan.

(a)

(b)

Fig. 4: C-SAM and surface microscopy image (below).

Another previous work on C-SAM is shown by Kiong in 2018 [25]in his paper. He used in this research on how to make images of samples at precise depth levels characteristically scanning horizontally across the silicon chip behind to obtain a planar view (C-scan) in a single scan. Effect of apply this C-SAM transmission acoustic imaging technique the multifarious flip chip set interface might be evaluated and observed more accurately. Fig. 6 represents the schematic diagram of flip chip package internal construction.

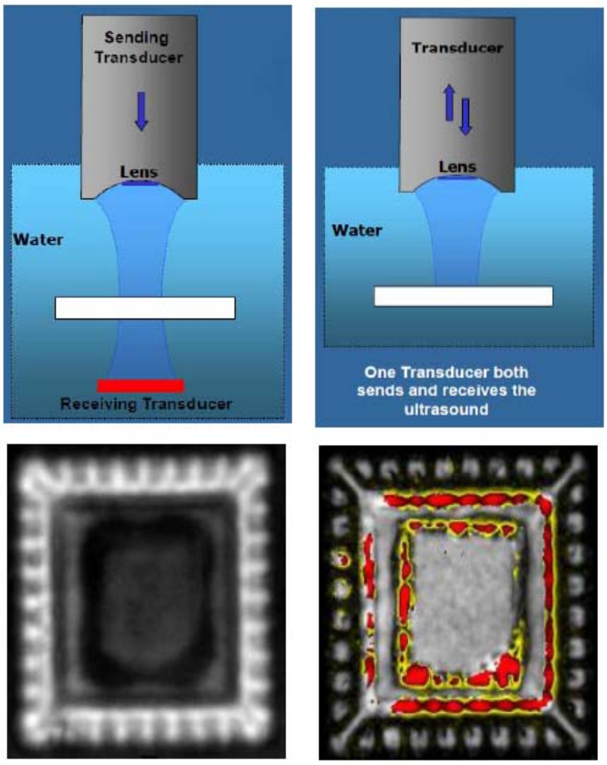



Fig.5: Differential between Reflection Mode (C-Scan) - right and Transmission Mode (Thru-Scan) - left (a) Schematic diagram, (b) image

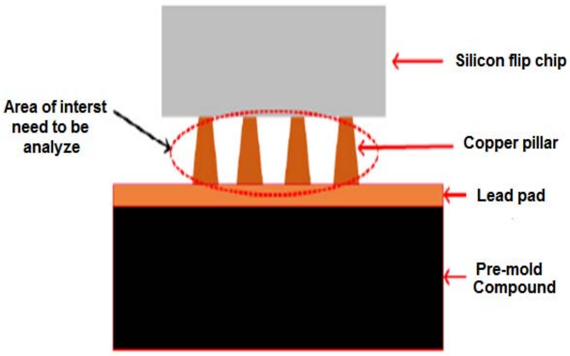



Fig.6: Schematic diagram of flip chip package internal construction.

### The principle of acoustic microscope for the electrical part

The transducer is the most important component of a SAM system. The latter transmits an ultrasonic signal (TX) on the target object at a small point [26]. The frequency of the transducer-generated ultrasonic signal is usually in the range 15–300 MHz up to GHz (for high detailed resolution but minimal penetration depth). In fact, the resolution and inspection depth of SAM measurements depends, in addition to the necessary details, not only on the acoustic frequency but also on the focal length of the transducer, the material properties and the complexity of the specimen 's structure under test [27].

Fractions of the acoustic energy incident by TX are reflected back when an acoustic impedance transition occurs, Z, (1) between the interfaces of internal materials under inspection (Fig.7a):

(1) $$Zi = pi.vi$$

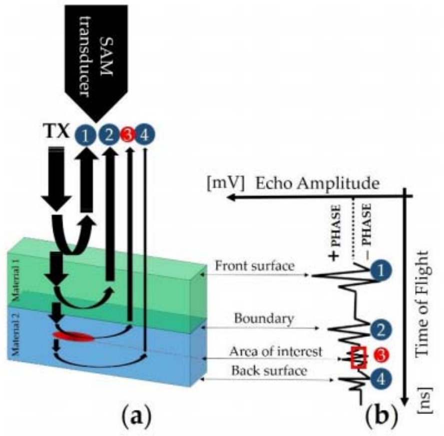



**Fig.7:** A-scan through the thickness of the sample under testing (target object) [27].

The index I is the form of material, and the density and the sound velocity of the material are the density and the sound velocity, respectively, [28]. The exact portion of the amplitude reflected back can be determined by the coefficient of reflexion, R, equal to (2):

(2) $$R = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

The higher the interface impedance mismatch, the higher the reflected signal strength (more brightness in the 2D image) which is determined by the amplitude of the echo. In the case of an air interface (Z = 0), the ultrasonic wave is totally reflected; thus, SAM is extremely sensitive to any trapped air in the sample under study.

In addition to calculating the amplitude of the sound wave reflected, the time required to detect the wave reflected back is also measured and shown in the so-called A-scan (Fig.7b). Details on the depth (location), d, of a possible defect in the material bulk can then be identified through:

(3) $$d = \frac{ToF.c}{2}$$

In which time of flight (ToF) the sound velocity of the material is observable in the A-scanner and c. The division by 2 is demonstrated by the sound wave back and forth trip from and to the SAM transducer. In Fig.7a 's generic sample structure, the series of reflected waveforms (Fig. 7b) consists of the # 1 signal, usually referred to as the front surface, i.e., the fifth interface. According to the interface between material 1 and material 2 the same behaviour is interconnected for signal # 2. The waveform # 3 will be viewed as an area of interest. The red box (data gate) indicates the information range, which is located over this signal or group of evaluation signals. The signal # 4 is applied to the rear surface showing the sample 's edge. Then the echo signals are analyzed and interpreted using Equation (3) to determine the position of particles, voids, air bubbles, delamination, or cracks.

Thus, 2D or 3D-dimensional representations of the internal structure are accessible via the pulse-reflection process, in which the impedance mismatch between two materials contributes to an ultrasonic beam reflexion (Fig.8). Phase inversion of the reflected signal may allow discrimination of delamination (nearly zero acoustic impedance) from inclusions and particles, but not from air bubbles, which display the same behaviour of impedance as delamination. In the case of applying SAM to the US probe acoustic stack, phase inversion may be influenced by multiple reflections due to multilayered structure, so it is difficult to relate the phase inversion to delamination or bubbles located in deeper interfaces.

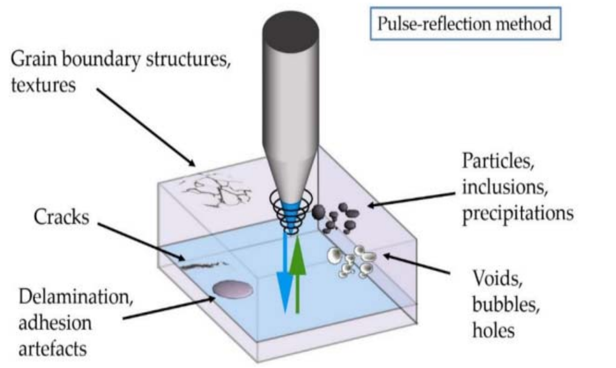



Fig.8: Defect detection and sample interaction (image courtesy of PVA TePla Analytical Systems) [29].

In High Definition SAM (Fig. 9) different types of analysis modes are available. A-scans, B-scans, and C-scans are the principal three types. Each offers varying details on the quality and structure of the sample. The A-scan is echo signal amplitude over ToF. The transducer is connected to the SAM's z-axis. By changing the z-position with respect to the sample under examination that is mechanically fifixed, it can be centered on a particular target layer located in an region that is hard to reach. The B-scan presents a longitudinal cross-section of the sample with the depth information being visualised. If it comes to detecting damage in the cross section it is a really useful function. A C-scan is a widely used scanning mode that provides 2D images (slices) of a target layer at a given sample depth; multiple equidistant layers are feasible via X-scan mode.

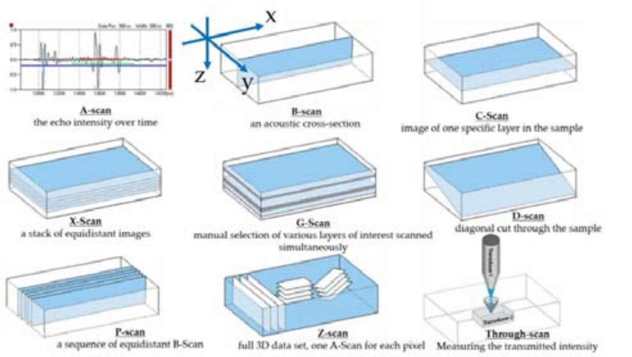



Fig.9: Scan modes of SAM (image courtesy of PVA TePla Analytical Systems) [29].

## Conclusion

The reviewed the several keywords of the SAM, CSAM, and C-SAM had been done. It shows that these three techniques have different and similar property and afford various effect of the material samples. In this paper, it shows that to use the failure analysis method for valuation of the flip-chip packages in manufacturing quality control of electronic devices with better condition in a faster in time, large sample size, not so expansive and automated way area is required. The user of any technique depends on the required objective of the researcher and the application, by applying the FA for both techniques, it can affect to decrease the cost by keeping the undesired failure defected material. Further, it can reduce the time to solve the problem in the IC region in semiconductor manufacturing.

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