Imaging and Characterization of Thick Production-Line Microelectronic Components using Transmission Acoustic Microscopy

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The interfacial regions of four types of production-line microelectronic components (die-bonded transistor headers, high power silicon transistors, chip-resistors, and multilayer chip-capacitors) have been examined using a transmission scanning acoustic microscope operating at 150 MHz and a combination of modes. Flaws, voids, and defects in these components have been detected. Some characterization of these defects has also been obtained.

INTRODUCTION

The characteristics of material joints, bonds, and composites are greatly influenced by the elastic faults such as stress distribution, microstructures, defects, and voids which occur in their interfacial regions. It is thus desirable to detect, identify, and ultimately characterize these faults using acoustic techniques. We had earlier employed a transmission-type scanning acoustic microscope (SAM) (See Fig. 1), operating at 150 MHz, to image the interfacial regions of a number of specially made joints of large thickness. Also, by using a combination of the amplitude and the phase modes of operation with this microscope, we were able to map the acoustic velocity and the attenuation coefficient distributions in the bond layer of a thick adhesive joint. Mapping of these acoustic parameters is important because the strength of an adhesive bond has been shown to be closely related to them. Detection of defects and flaws in such thick specimens was facilitated through operation of the microscope in a combination of confocal and nonconfocal modes at a relatively low acoustic frequency, namely, 150 MHz. In a nonconfocal mode of operation, the separation between the transmitter lens and the receiver lens is set slightly larger or smaller than the sum of the two focal lengths. Using this mode of operation it is possible to obtain large depth of focus and, thus, image thick specimens at a slight reduction in spatial resolution. The series of acoustic images shown in Fig. 2 for a test specimen serve to illustrate this capability. The test specimen was a copper plate of 0.5 mm thick with the characters CJM and the pattern of various shapes etched on one face, and the characters NSF and straight bars on the other.

In this paper, we report further progress which has been made using this acoustic microscope. Emphasis of the present work is placed on the imaging and the characterization of the interfacial regions of thick production-line microelectronic components.

CAPABILITIES OF THE SCANNING ACOUSTIC MICROSCOPE

The modes of operation and key parameters of the scanning acoustic microscope (SAM) employed in this study are listed as follows:

Modes of Operation: Transmission Mode

- Amplitude
- Phase
- Confocal
- Nonconfocal

Acoustic Lenses: f/4 (in water), focal length in water = 4 mm
Spatial Resolution: 30 μm in water at 150 MHz (confocal)
Field of View for the Sample: 3 x 4 mm
Magnification of Acoustic Images: 35
Total Electrical Throughput Loss (without specimen): 55 DB
Dynamic Range: 30 to 50 DB at 1 mW (0 dBm) input electric power, depending on the sample that has been examined.

IMAGING AND CHARACTERIZATION OF DISCRETE MICROELECTRONIC COMPONENTS

Four types of thick production-line microelectronic components have been examined using one or a combination of the modes of operation listed in Section II.

Die-Bonded Transistor Headers

The voids in the bond region of a die-bonded transistor header (See Fig. 3(a)) is known to result in "hot spots" and thus early failure of the power transistor. The spatial resolution and contrast obtainable with the existing instrument based on x-ray radiography are less than desirable. The three-dimensional locations of small voids (not detectable by the x-ray method) have been determined using the SAM (See Fig. 3(b)). Fig. 3(c) shows that one of type B headers has a very poor bond while the other has practically no bond at all.

High Power Silicon Transistors

"Alloy spikes" at the silicon-alloy interface are known to cause undesirable effect in drastically lowering the breakdown voltage of high power transistors (See Fig. 4(a)). Their location and size (See Fig. 4(b)) have been determined nondestructively from the data obtained using both the amplitude and the phase-mode of operation of the SAM (See
Estimated sizes of the particular alloy spike detected are $h = 15 \mu m$ and $b = 100 \mu m$.

**Thick-Film Circuits And Thin-Film Chip Resistors**

In thick film circuits, the particle distribution in the film will affect the component value, and the defects in the film may reduce their reliability. The acoustic micrograph shown in Fig. 5(c) of a thick-film resistor (Fig. 5(a)) suggests a nonuniform distribution of the resistive particles and some defects in the resistor layer. Fig. 6(b) shows the acoustic micrograph of a thin-film chip resistor (Fig. 6(a)) in which the defects of the multi-layer structure (alumina substrate-NiCrSiO-Coating) are clearly seen.

**Multilayer Chip Capacitors**

A variety of multilayer chip capacitors including those made of BaTiO$_3$ and ceramics have been examined. Defects such as voids and debonds which occur at the interfaces and inclusions which occur in the dielectric have been detected by recording a series of acoustic micrographs as the specimen was translated along the lens axis. For example, the acoustic micrographs shown in Fig. 7(c) reveal clearly the defects in different cross-sectional planes of a BaTiO$_3$ chip capacitor (Fig. 7(a)) furnished by American Technical Ceramics. A typical amplitude profile of the transmitted acoustic energy (Fig. 7(d)) indicates that the acoustic wave suffers an attenuation of about 15 db when it impinges upon a defect located at $P$. This type of defect may result from some kind of inclusion. The optical image for an appropriate cross-section is shown in Fig. 7(b). Note that the sizes of the dark spots in the optical image are comparable to that of the acoustic micrograph. We have also observed that the acoustic attenuation associated with the voids or the debonds are greater than 35 db. Finally, it should be noted that the scanning laser acoustic microscope (SLAM) had also been employed to examine the ceramic chip-capacitors.

**CONCLUSION**

We have demonstrated that a scanning acoustic microscope, operating at transmission mode and 150 MHz, is capable of nondestructively detecting defects deep inside thick production-line multilayer microelectronic components. We have also succeeded in identifying and characterizing some of the defects such as voids, alloy spikes, debonds, and inclusions.

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**REFERENCES**


Fig. 1 Block diagram of a transmission scanning acoustic microscope.
Fig. 2 Acoustic images of a test specimen obtained at different adjustment of focus: (a) - (e) short depth of focus centered at different planes, (f) long depth of focus.

Fig. 3(a) Top view of die-bonded headers obtained by optical microscope
(b) Acoustic images of die-bonded header (A type: thickness = 42 mils)
   (I) Long depth of focus centered at bond region
   (II) Short depth of focus focused at bond region
(c) Acoustic images of two other die-bonded headers (B type: thickness = 30 mils)
   (I) Very poor bonding
   (II) No bonding at all
Fig. 4(a) Top view of the production-line power transistor under study (thickness: 58 mils).
(b) Cross-sectional sketch of the power transistor.
(c) Acoustic amplitude images of a portion of the power transistor obtained with acoustic beam focused at the silicon alloy interface.
(d) Acoustic phase variation (upper curve) and acoustic amplitude variation (lower curve) along line C-D of Fig. 4(c).
Fig. 5(a) Top view of the thick-film circuit (thickness: 44 mils)
(b) Cross-sectional view obtained by optical microscope
(c) Acoustic amplitude variation along line E0F

Fig. 6(a) Top view of thin-film chip resistor (thickness: 19 mils)
(b) Acoustic Micrograph
(c) Acoustic amplitude variation along line EF
Fig. 7(a) Top view of a BaTiO₃ chip-capacitor (thickness: 74 mils)
(b) Cross-sectional view of the chip capacitor
(c) Acoustic micrographs
(d) Acoustic amplitude variation along line AB