Basic Principle of a Scanning Acoustic Tomograph

What is Ultrasonic Inspection?

Ultrasonic waves are sound waves above 20 KHz that cannot be heard by the human ear. A non-destructive method of examining the inside of industrial parts using ultrasonic waves is called an ultrasonic examination method. Compared to other examination methods, this examination method has higher ability to detect cracks and disboding, and is widely used for evaluating the reliability of electronic parts and performing breakdown analysis these days**.**

(1) Principle of defect detection using ultrasonic

Figure 1 shows the principle of ultrasonic measurement.
A piezo-electric device inside an ultrasonic probe vibrates when a pulse voltage is applied to it. When the ultrasonic waves generated by this vibration are directed at a sample immersed in water, they propagate through the sample as elastic waves. If there is a void, crack or other abnormality in the sample, the acoustic impedance will change, resulting in reflection and refraction of the ultrasonic waves. The sample in this figure is an IC package, and such behavior of the ultrasonic waves occurs when there is a void at the interface between the silicon chip and the molded resin or inside the resin, a cracked chip, and so on.

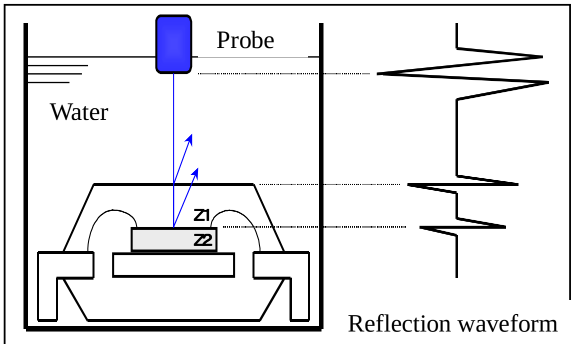


Fig. 1 Principle of ultrasonic measurement.

The acoustic impedance is expressed as the product of the density and the speed of sound, as shown in equation (1).

$$Z = \rho \cdot C \ \ldots (1)$$

ρ : Density of the sample
C: Sound speed of the sample

In addition, the reflectivity is obtained from equation (2) using the acoustic impedance.

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

The reflectivity differs according to the combination of the two materials in contact with each other, and the difference between the conditions is manifest as the difference between the intensity values of the reflected echoes. Particularly, in the case of air, which has a very low density, the reflectivity is about 100%, so this is a major factor for accurately measuring air gaps. Generally, pulse waves are emitted from the probe at intervals of 0.1 to 10 ms, and between intervals of emission the probe receives the echoes reflected from inside the sample, enabling it to detect flaws.

		Air	Resin	Si	42 Alloy	Silver Paste	Al	Cu	Au	H_2O
	Z	0	6.76	20.04	40.91	11.7	16.9	41.83	62.53	1.48
Air	0	−	100	100	100	100	100	100	100	100
Resin	6.76	100	−	50	71	27	43	72	80	64
Si	20.04	100	50	−	34	26	9	35	51	86
42Alloy	40.91	100	71	34	−	56	42	1	21	93
Silver paste	11.7	100	27	26	56	−	18	56	68	78
Al	16.9	100	43	9	42	18	−	42	57	84
Cu	41.83	100	72	35	1	56	42	−	20	93
Au	62.53	100	80	51	21	68	57	20	−	95
H_2O	1.48	100	64	86	93	78	84	93	95	−

(2) Feature of ultrasonic inspection

1. **The air gap detection performance is far superior to that of other measurement methods.**
The detection limit that can be currently confirmed is 5 nm (bonded silicon wafers). Moreover, this figure does not depend upon frequency. If there is an air gap of at least 5 nm, it can be detected regardless of whether the frequency is 15 MHz or 200 MHz.

2. **The surface resolution is 1/2 of the beam diameter, as a rough guide.**
It is difficult to give an immediately reply to the question “What is the minimum size of defect that can be detected?” because it differs depending upon various conditions. As a rough indication, however, half the diameter of the probe beam is used. In actual measurement, first the frequency that is most suitable for measurement is ascertained.

3. **The closer the defect is to the surface, the smaller is the defect that can be detected.**
The higher the frequency, the higher are both the surface resolution and the depth resolution, but the greater is the attenuation. Consequently, in general there is a tendency for the frequency to be reduced in inverse proportion to the thickness of the sample.

4. **A relative evaluation method is employed.**
As mentioned above, measurement is based on a comparison of the reflected echoes.
Evaluation based on comparison, such as comparison between a good part and a defective part, or between a part prior to testing and a part after testing, enables a sound judgment to be made. When evaluating a part for the first time, it is recommended that after measuring it once, you cross-check it by a destructive examination such as cross-section grinding. If it is possible to confirm that the results of measurement are correct, you can use the examination method with peace of mind.

(3) Samples that are often measured by ultrasonic waves

As mentioned above, ultrasonic measurement has very high detection sensitivity to air. We have verified that a reflection is obtained with all air gaps down to 5 nm. Consequently, this method of measurement is highly suitable for detecting cracks, voids, and other defects inside the sample, and also for checking the bonding condition at the interface between two semiconductor layers. The main current applications are indicated below:

(Semiconductors and electronic components)

* Interface disbonding of IC package, resin voids, chip cracks, package cracks, die attach evaluation, and heat sink bonding evaluation
* Evaluation of CSP and flip chip underfill
* Chip capacitor (laminated ceramic capacitor) inter-layer disbonding
* Chip cracks on IC cards
* Silicon wafer bonding evaluation
* Evaluation of internal substrate defects and thin-film adhesion
* Evaluation of liquid crystal substrate

In addition to the above, examination of internal defects in various electronic components, and reliability test evaluation

(Metals)

* Internal cracks, voids and foreign matter
* Adhesion evaluation (evaluation of adhesion of target material to backing plate, and so on)
* Evaluation of inclusions (aluminum in thin steel plate, etc.)
* Evaluation of welding

(Chemical products and ceramics)

* Evaluation of the internal condition of injection moldings (flow, welds, etc.)
* Orientation of filler
* Internal voids and cracks
* Inter-layer disbonding in CFRP and FRP

(4) Precautions concerning measurement

1. **The surface of the sample should be as flat as possible.**

When performing measurement based on reflection, the target position will always be affected by the part above it. For example, if there is a laser marking or irregularity on the surface, the ultrasonic beam will be scattered and irregularly reflected by such a part. Compared to a flat surface, the intensity of the ultrasonic waves that enter a sample with an irregular surface is low, and the incidence conditions change, so the reflected echo is also affected. Needless to say, the image is also affected, making it difficult to make a judgment.

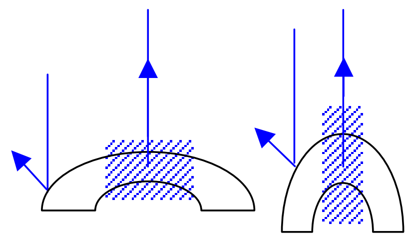
2. **It is not possible to detect internal defects that are finer that the surface roughness.**

For example, if the surface roughness can be judged visually, it will be impossible to detect internal voids of several tens of mm in diameter.
The reason for this is the same as 1.

3. **Difficult samples for measurement**

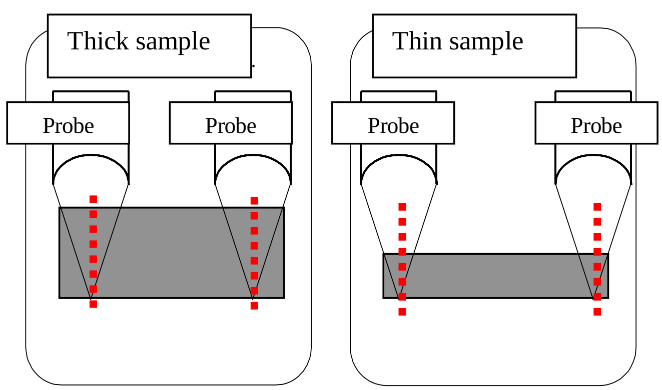
*** Samples that have rounded surfaces can be measured only the part of them.**

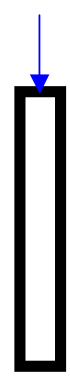
The entire ultrasonic wave enters the sample and is reflected from it, enabling an image to be obtained only if the surface is perpendicular to the probe. At other parts, irregular reflection occurs, and the reflected echo is small, preventing an image from being obtained. The smaller the radius of curvature of the surface, the smaller is the area from which an image can be obtained.
(An image can be obtained from the blue shaded area shown in the figure at right.)



*** An image of the end parts is difficult to obtain.**

At the end parts of the sample, the ultrasonic beam often cannot enter the sample and is irregularly reflected, making the image difficult to see. Such an area that is difficult to see is called dead space. As shown in the figure at bottom left, the thicker the sample the greater is this dead space (part outside the red line). Consequently, if the sample has a small surface area and a large thickness, as indicated by the fire at bottom right, it will be difficult to measure.





*** If possible, measure from the side that has the larger surface area.**

In the case shown at right, if measurement can be performed from either side, a clear image as far as the end parts can be obtained by locating the sample as shown in (1).

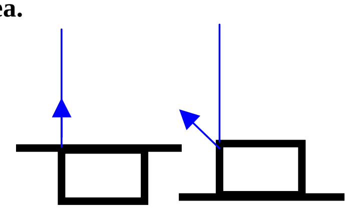
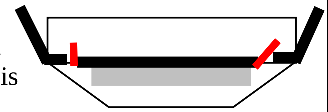
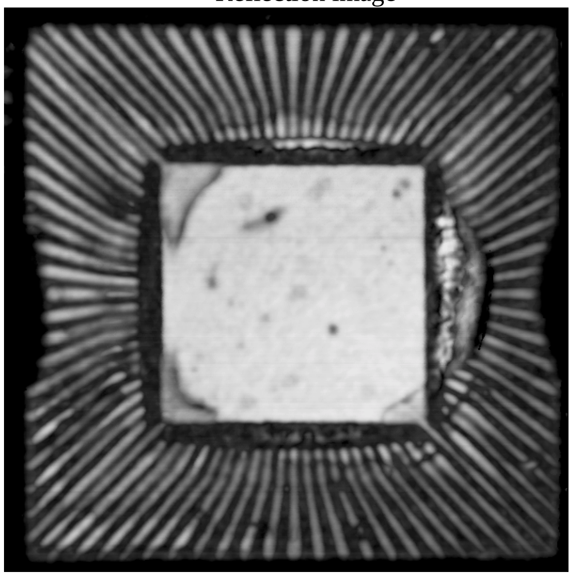


Image 1: Image of a crack in an IC package

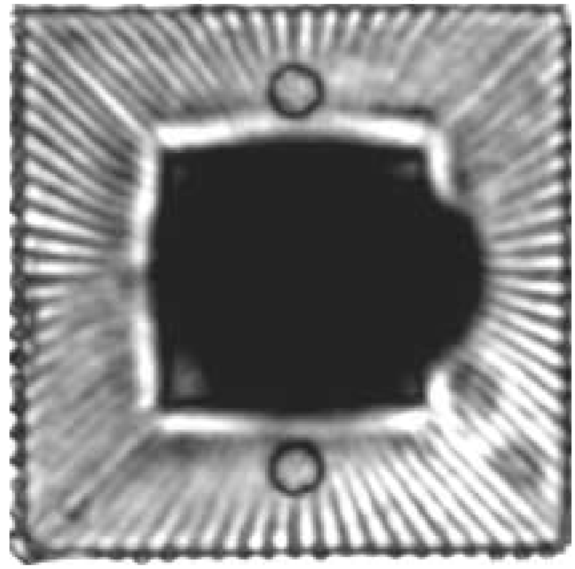


There is a package crack in the resin at the back of the die pad. Particularly, if you look at the area on the right hand side of the image you can see that the lead frame is invisible, indicating that the crack is at the top.

Reflection image



Through transmission image



3D image

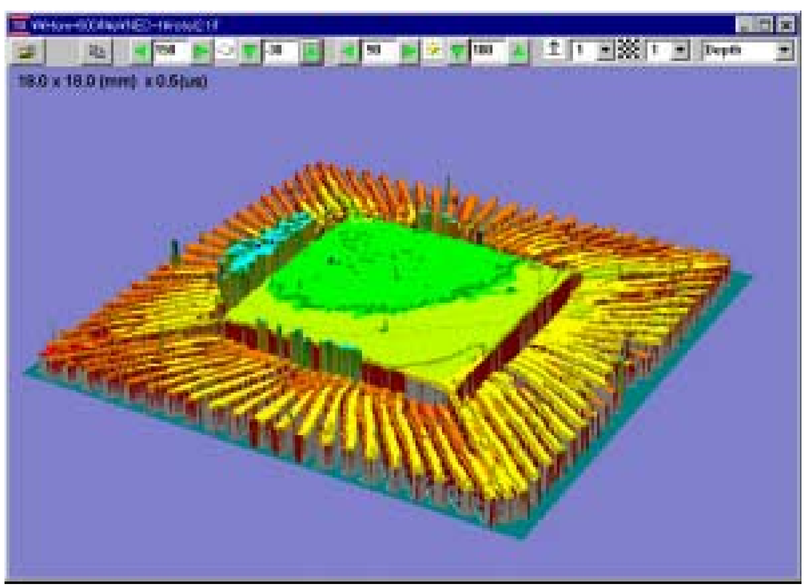
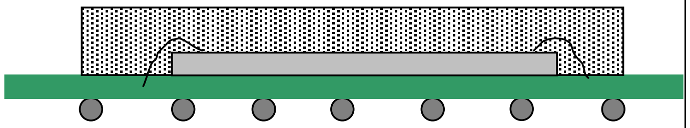
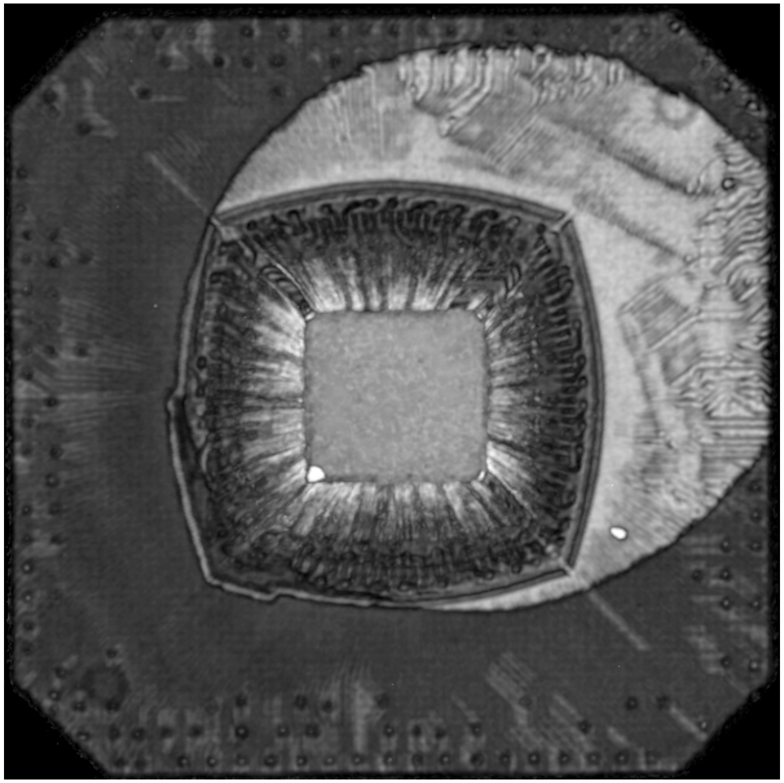


Image 2: Images comparing of BGA method and Through- transmission method

Ultrasonic waves do not travel readily through a glass epoxy substrate, hence it is difficult to perform an internal examination. Disbonding between the resin and the chip, and also between the resin and the substrate, is detected by means of a reflection image (left side). In contrast, cracks inside the substrate are evaluated using the transmission technique.



Reflection method



Through transmission method

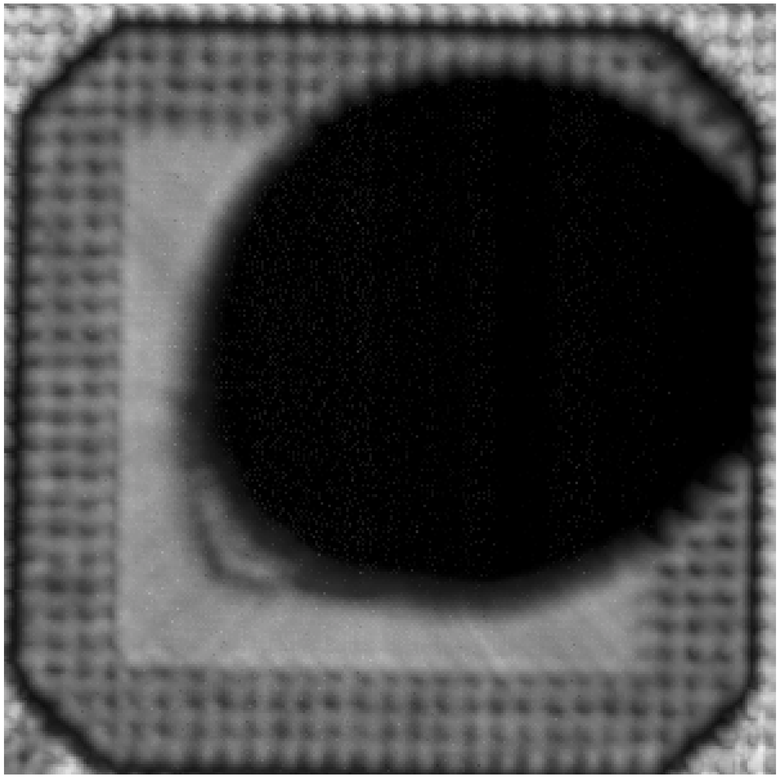
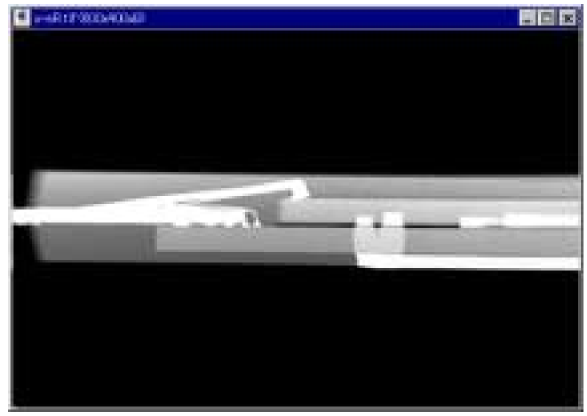


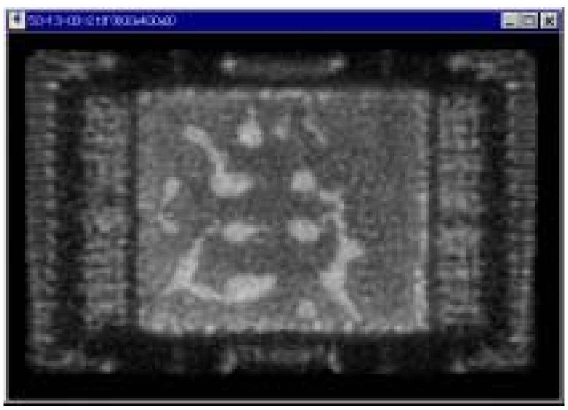
Image 3: Images comparing between X-ray and ultrasonic inspection of a stacked IC

Ultrasonic image (Focused on chip/ resin surface)

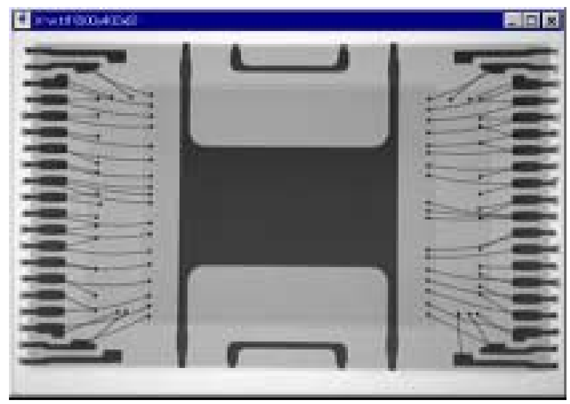
X-ray image (cross-section image)



Ultrasonic image (Focused between 1st and 2nd chip)



X-ray image (plane image)



Syntethic image

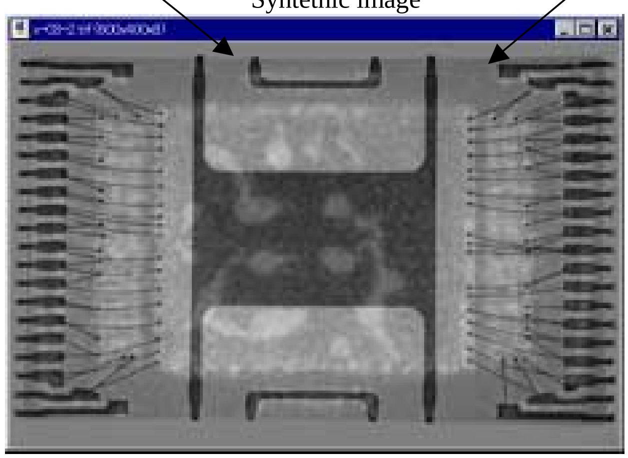
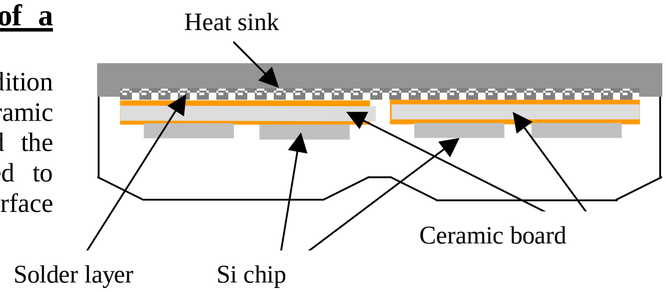
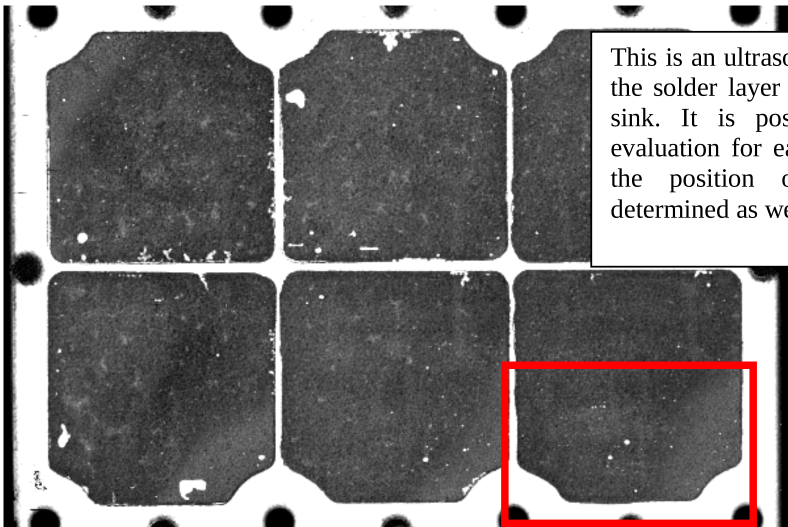


Image 4: Image of the bonding face of a power device (IGBT)

This image is used to examine the adhesion condition at the interface between the heat sink and the ceramic substrate and also between the substrate and the silicon of the semiconductor. It is also used to evaluate the adhesion condition at the interface between the substrate and copper or aluminum.





This is an ultrasonic image of a void in the solder layer at the rear of the heat sink. It is possible to perform an evaluation for each interface, enabling the position of a defect to be determined as well.

This is an X-ray image of the part of the above ultrasonic image enclosed by the red border. It contains all of the internal information, so the process of determining the location of a defect is difficult. However, when using ultrasonic, it is also possible to detect defects at points that cannot be detected using X-rays.

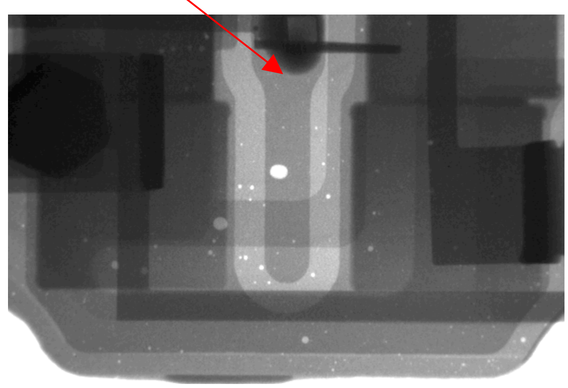
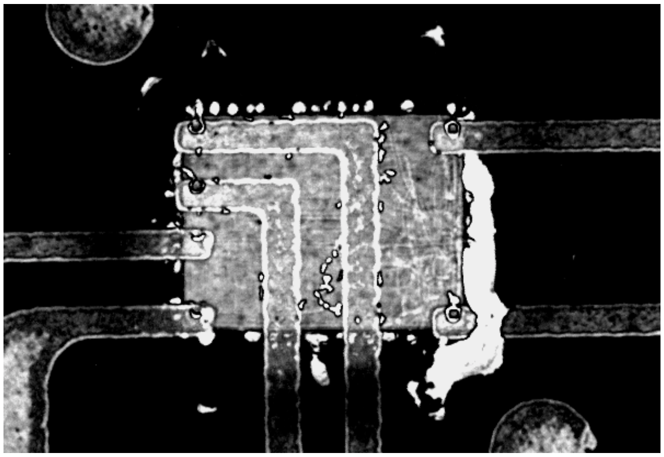
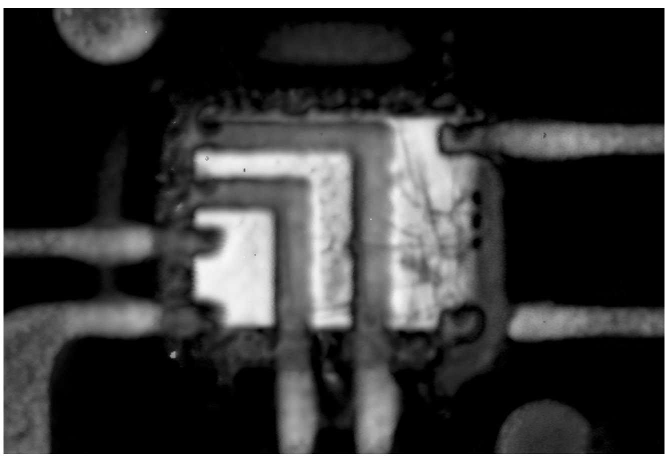


Image 5: Image showing cracks and disbonding in an IC card

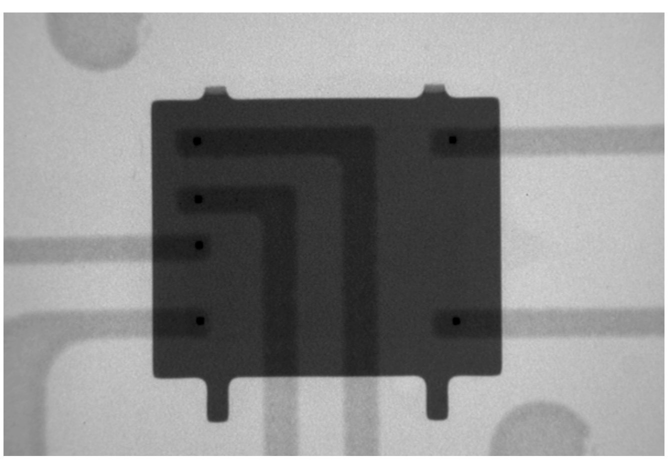
This is an image of a thin type IC card used for a telephone card. This product is expected to find increasing application from now on. It is examined in order to detect broken wires, cracks, disbonding, and other defects. On the other hand, X-rays are more advantageous for detecting broken wire on an antenna.



Ultrasonic image
(Crack measured by high-frequency probe)



Ultrasonic image
(Crack measured at shadows)



X-ray image

Image 6: High magnification image of an IC card (using high-frequency probe)

This is a smart card that has been in use for quite some time in Europe and the U.S. We peeled off the top of the card to reveal the chip, and performed measurement at 200 MHz. Both cracks and the chip pattern can be seen clearly.

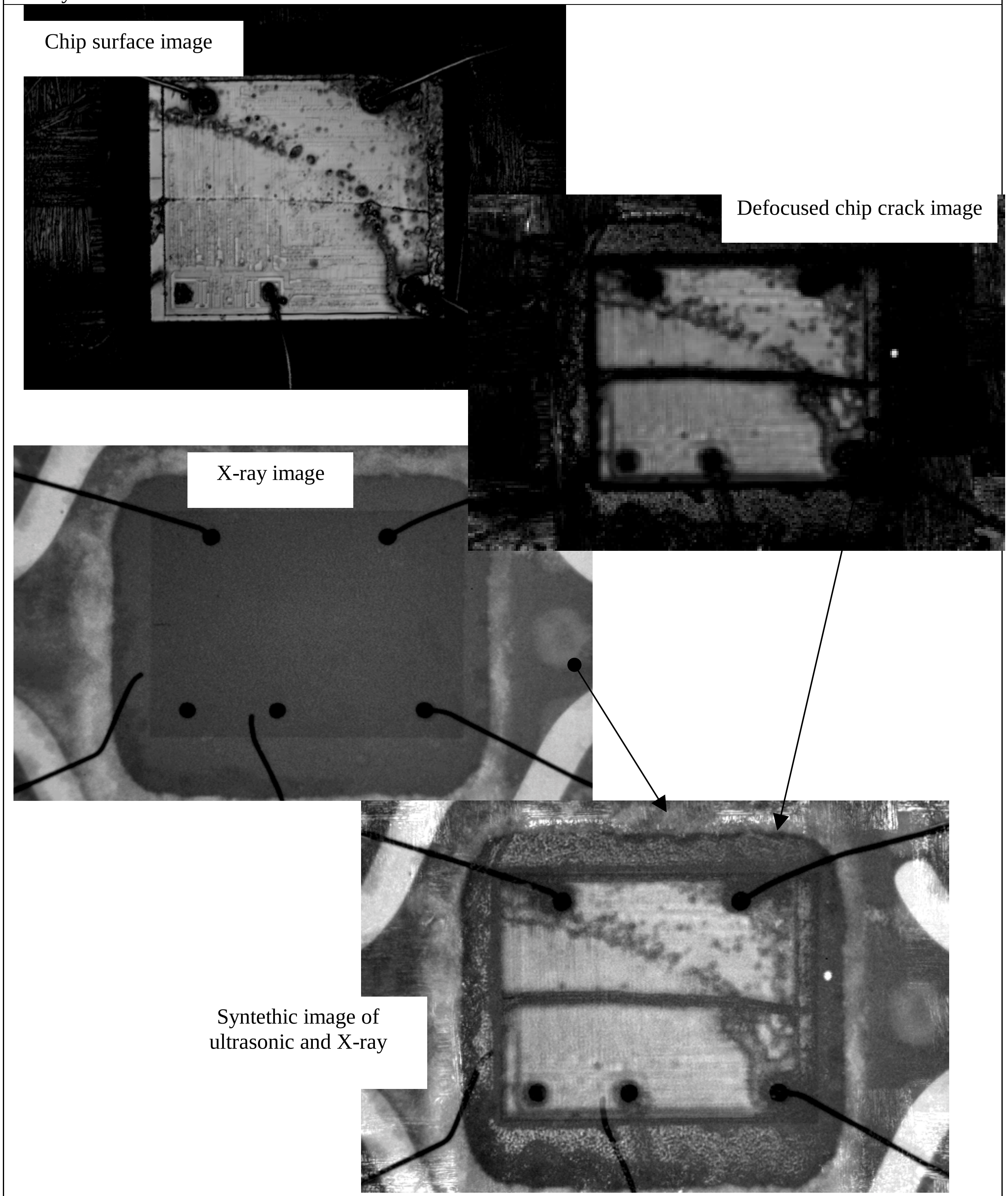
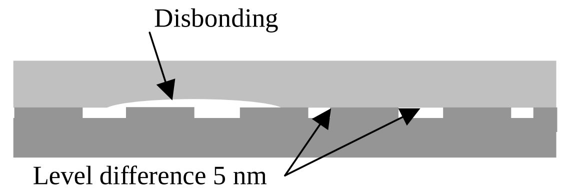


Image 7: Silicon wafer bonding image

Silicon itself causes little attenuation of ultrasonic waves, and also monocrystals are bonded to each other, so a silicon wafer as a sample is very easy to measure. This image shows one of the silicon crystals with a 5 nm step etched in it. This method enables large circular bonding defects and also clearances of as small as 5 nm to be detected, regardless of frequency.



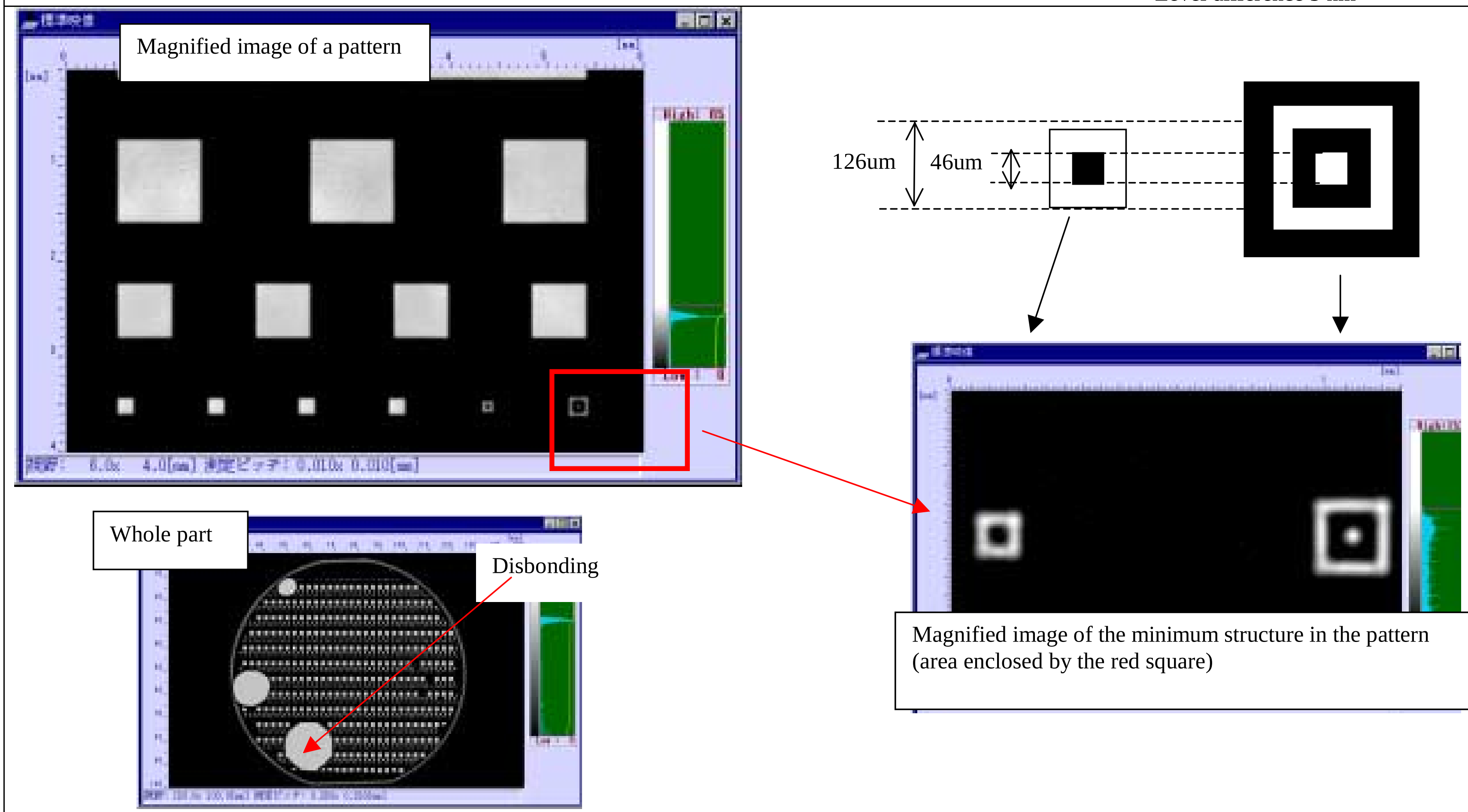
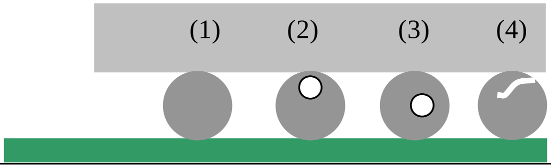
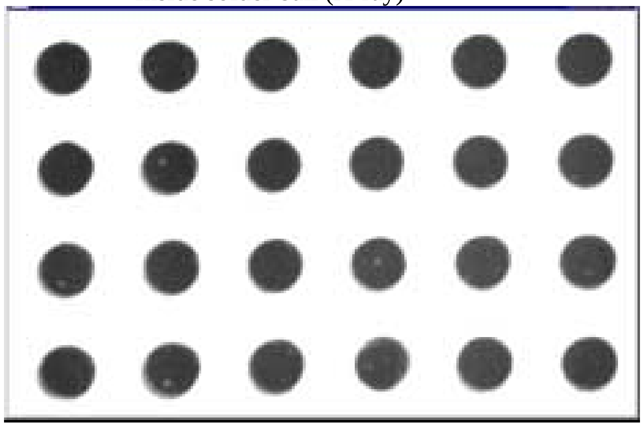


Image 8: Example of observing CSP-BGA solder balls

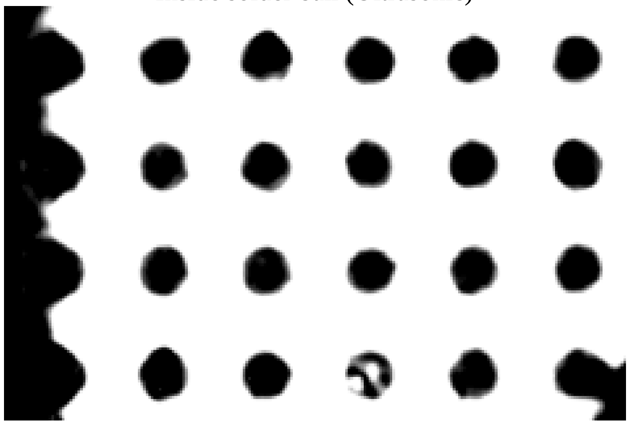
Normally, X-rays are more suitable for performing various evaluations of solder balls with the exception of the disbonding at the interface with the chip shown in (1) of the figure at right, in consideration of the shape of solder balls. However, voids can be detected even using ultrasonic waves. The balls that appear dark at the center part at the bottom of the image are indicative of the existence of cracks above them.



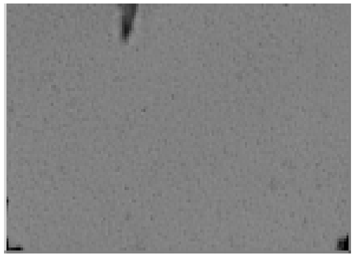
Inside solder ball (X-ray)



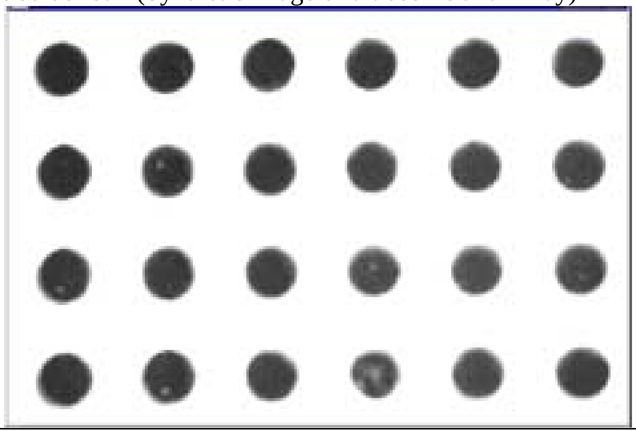
Inside solder ball (Ultrasonic)



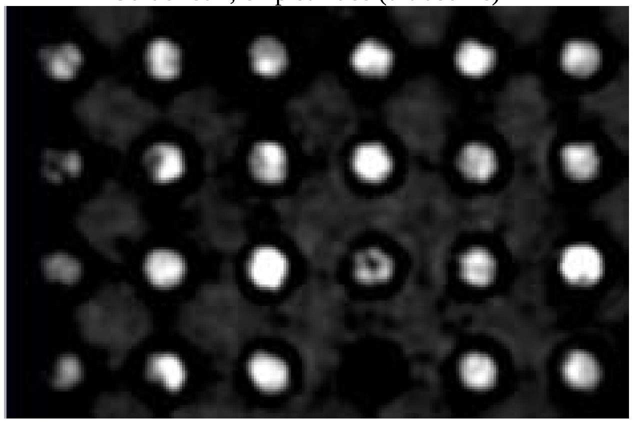
Chip surface (Iltrasonic)



Inside solder ball (Synthetic image of ultrasonic and X-ray)



Solder ball, chip surface (ultrasonic)



Chip rear side (Iltrasonic)

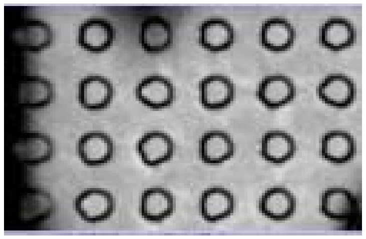
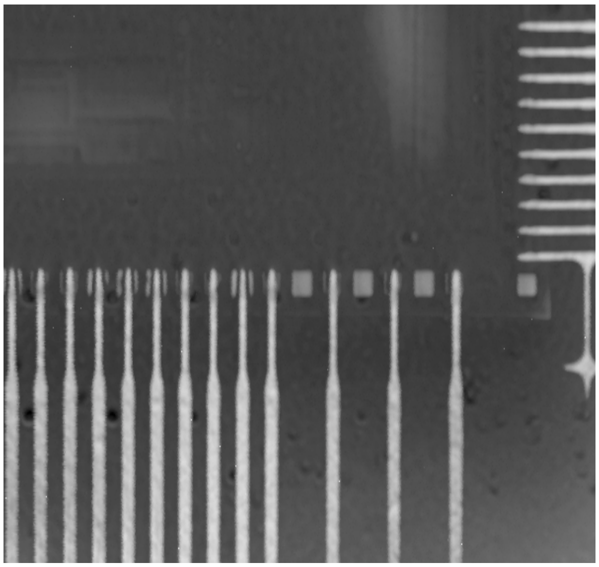


Image 9: Liquid crystal flexible substrate image

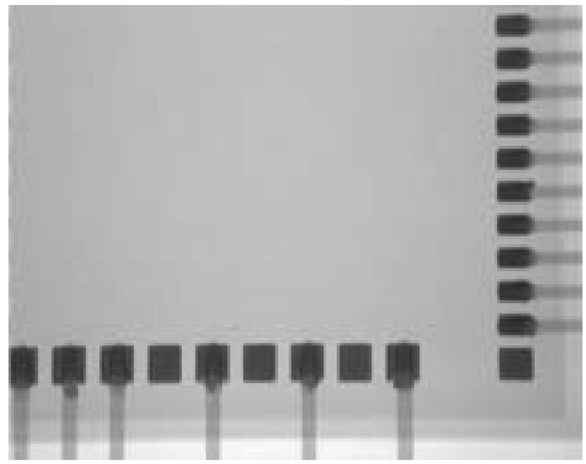
Air bubbles cannot be seen using X-rays, but can be observed using an ultrasonic wave of 140 MHz.

Observation of the IC bond from the flexible substrate side

Ultrasonic image

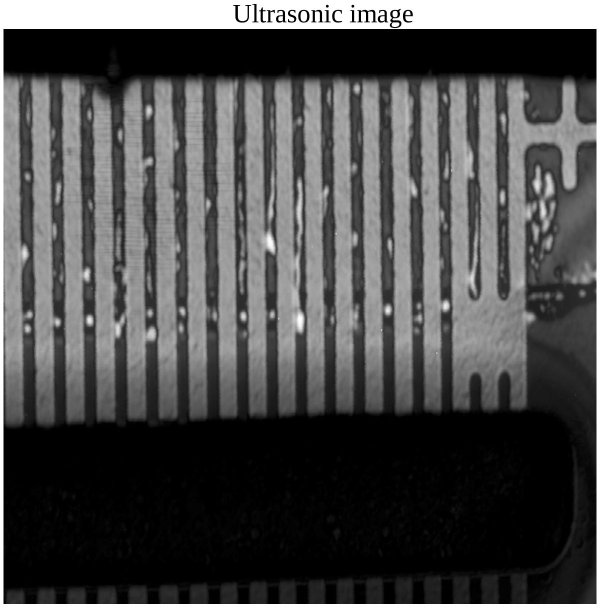


X-ray image



Observation of the bond between the flexible substrate and the glass from the substrate side

Ultrasonic image



X-ray image

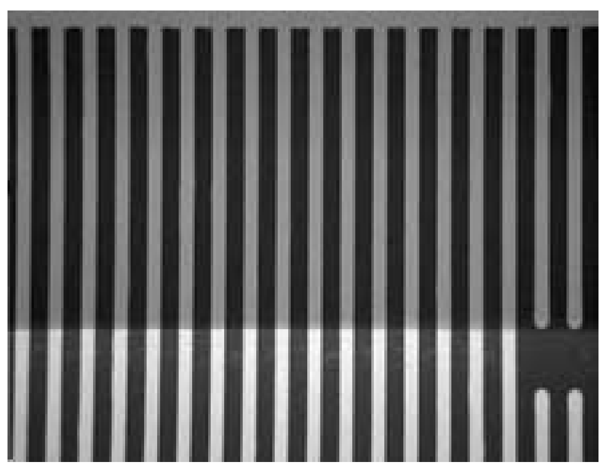
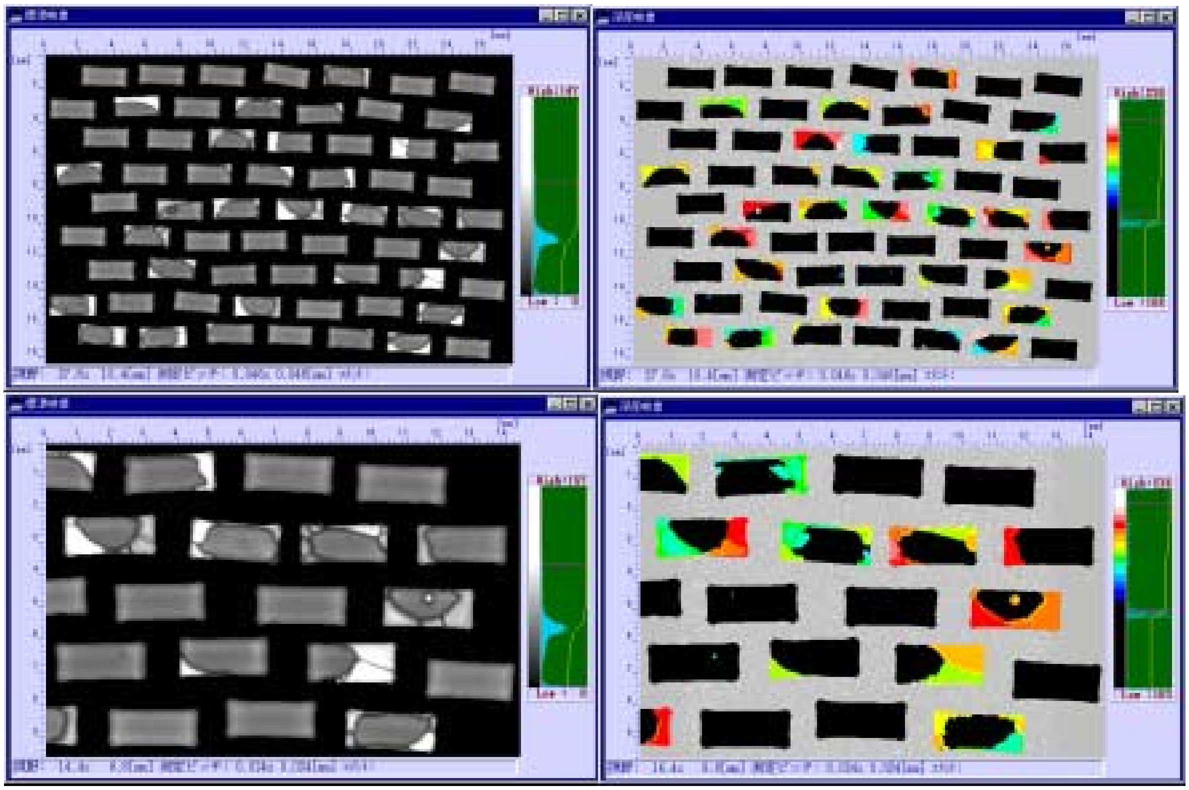


Image 10: Image showing disbonding between layers of a laminated ceramic capacitor (chip capacitor)

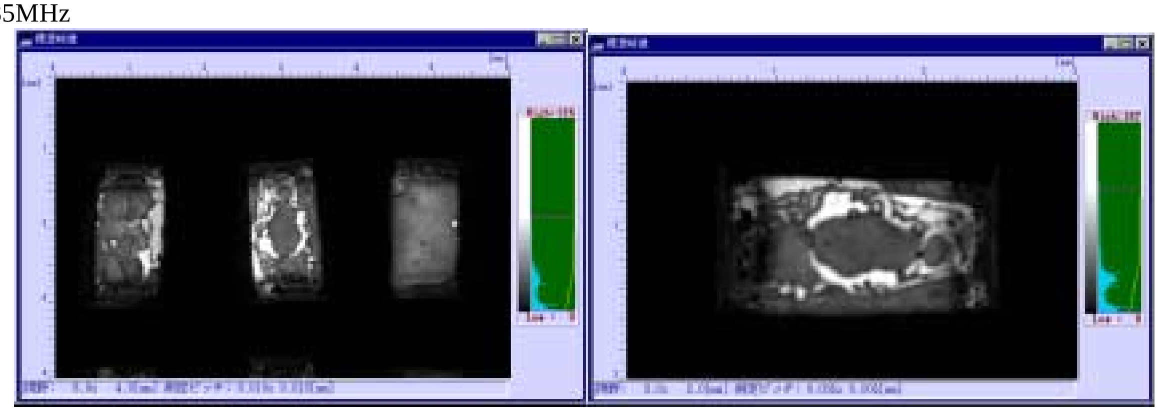
Normally, a depth image is used to check the existence of a defect and determine its position at the same time.

Reflection image | Depth image

50MHz



85MHz



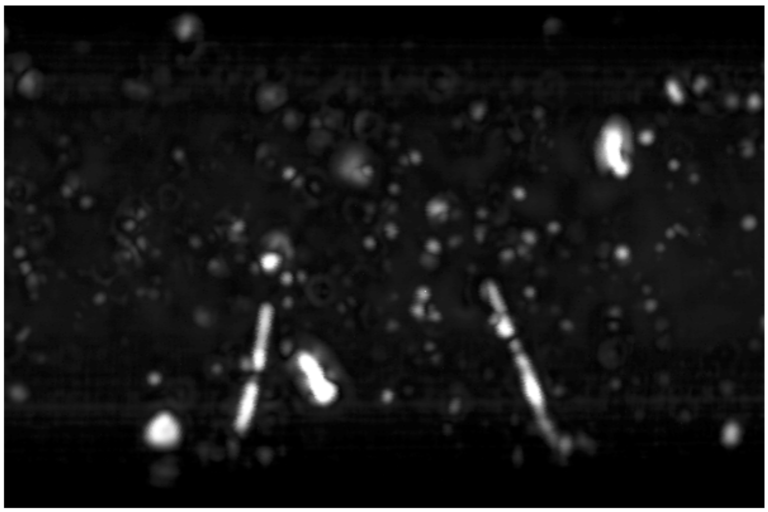
1mm

200 μm

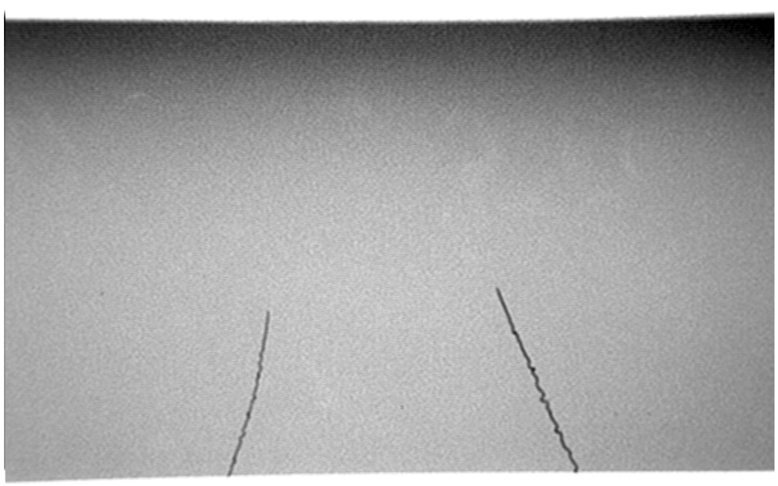
Image 11: Image of artificial defects in a ceramic capacitor

This image shows a sintered ceramic silicon nitride capacitor of 5 mm thickness with tungsten wires of 40 mm (left) and 50 mm embedded roughly at its center. The gap formed around each wire is observed with ultrasonic, and naturally occurring air bubbles in the vicinity can be seen. If X-ray observation is performed, the wires can be seen clearly but the air bubbles are virtually invisible.

Ultrasonic image



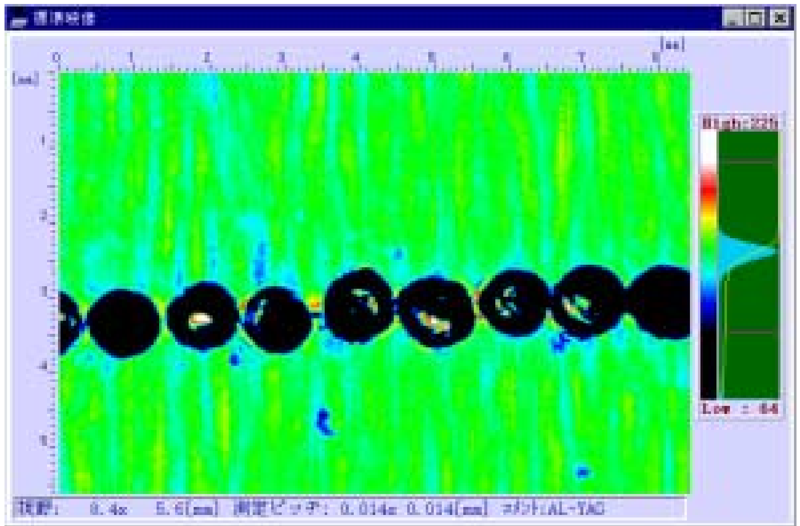
X-ray image



<u>Image 12: Surface of aluminum plates spot-welded using a YAG laser</u>

Images showing two aluminum plates of 0.8 mm thickness welded using a YAG laser
Ultrasonic image = Blow holes inside the spot
X-ray image = Cracks in the spot

Ultrasonic image



X-ray image

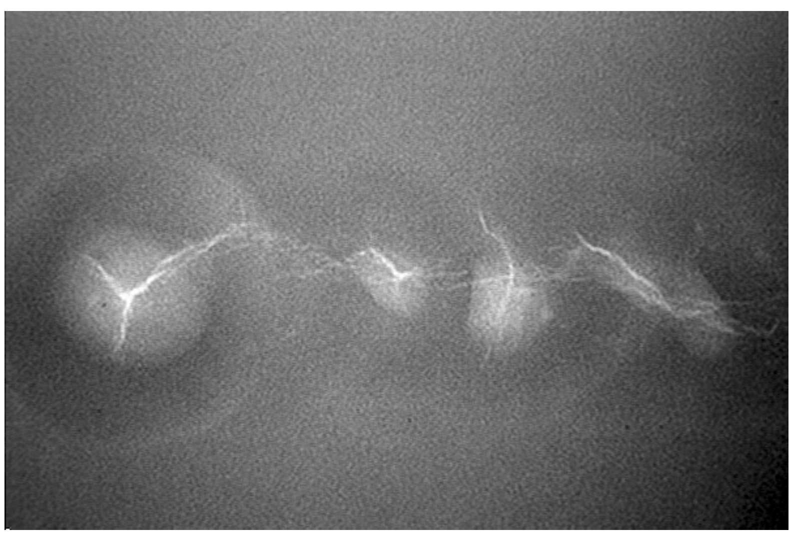
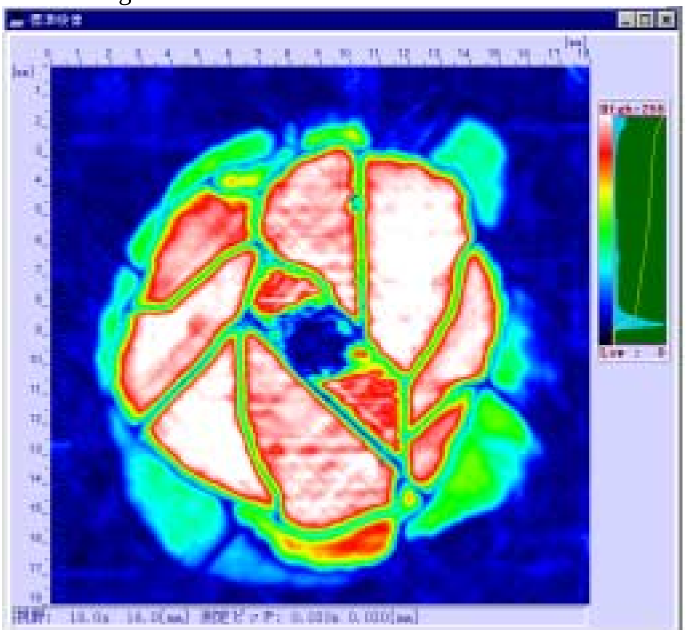


Image 13: Image showing disbonding in a CFRP laminated plate

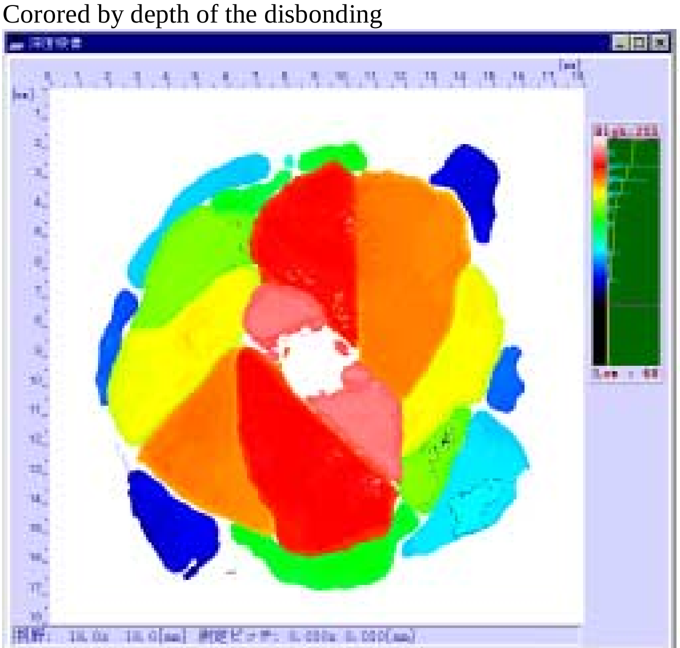
The fiber direction was changed 45 degrees at a time, and a steel ball was made to collide with the center part of the bonded CFRP plate. The thickness of each layer is about 0.15 mm. It can be seen that the disbonding increases with depth.

Reflection image



Depth image

Corored by depth of the disbonding



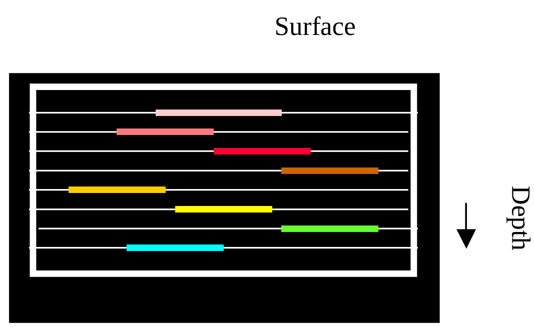
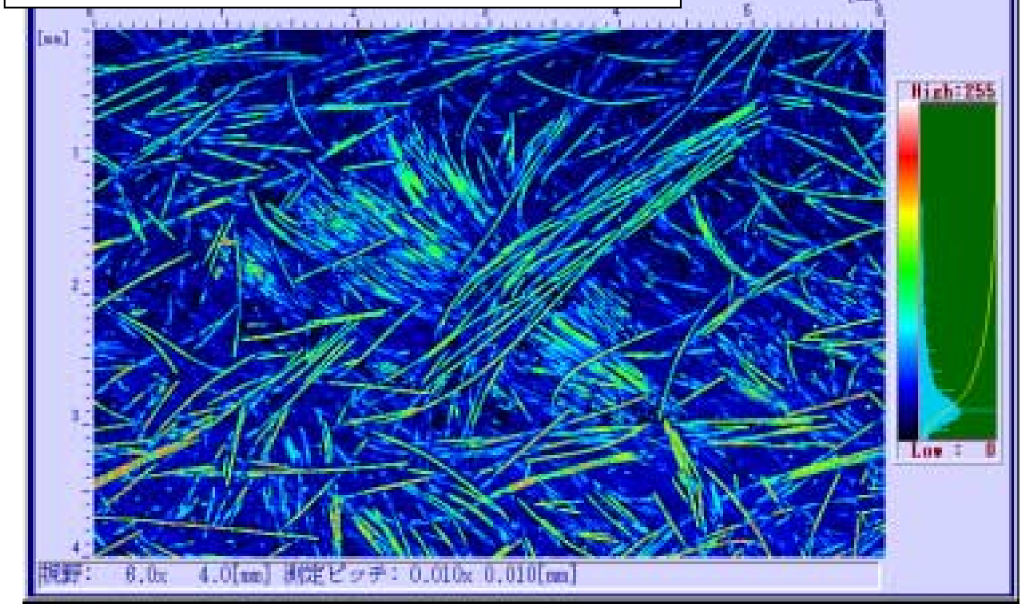


Image 14: Observation image of resin filler

The condition of the resin filler can be observed by generating a high-frequency ultrasonic image of the surface of the resin. Previously, observations were made by dissolving the resin alone using acid, for example. It is now possible to perform non-destructive observations. The size of the filler in this case is about f10 mm.

Long fiber type. The fibers are bunched together and overlap each other or are twisted.



Short fiber type. The filler content is several %, facilitating observation.

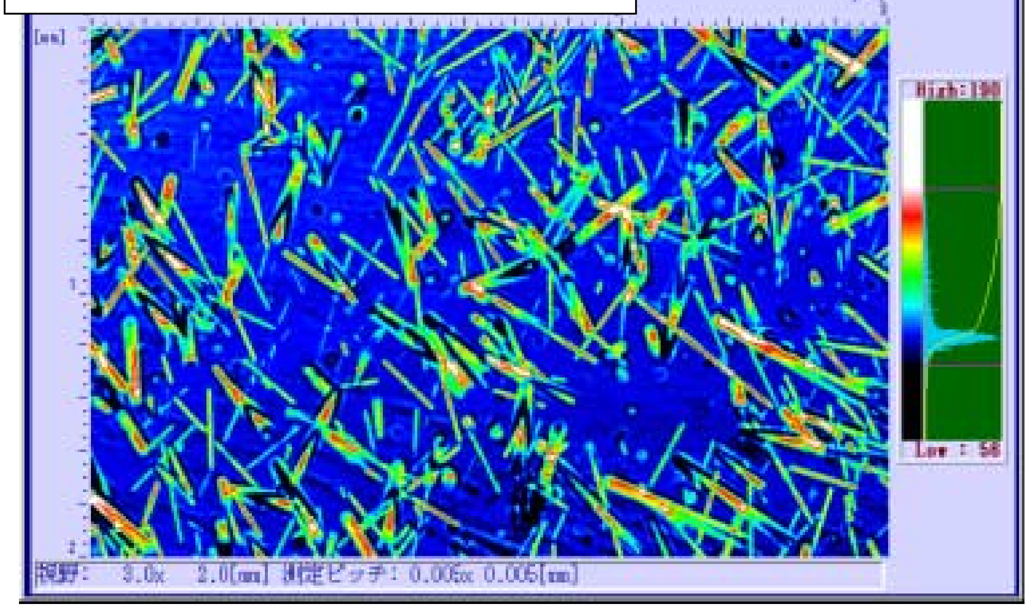
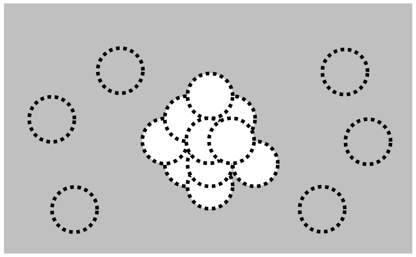


Image No.15: Image showing dispersion and cohesion of the filler in the resin

Unless the filler in the resin is dispersed evenly, the strength of the resin will vary from place to place, which can lead to breakage. The grains of the filler are several mm, and for normal ultrasonic measurement this is below the detectable limit, however when a large number of grains cohere, the resulting grain size is such that an image can be obtained without problem.

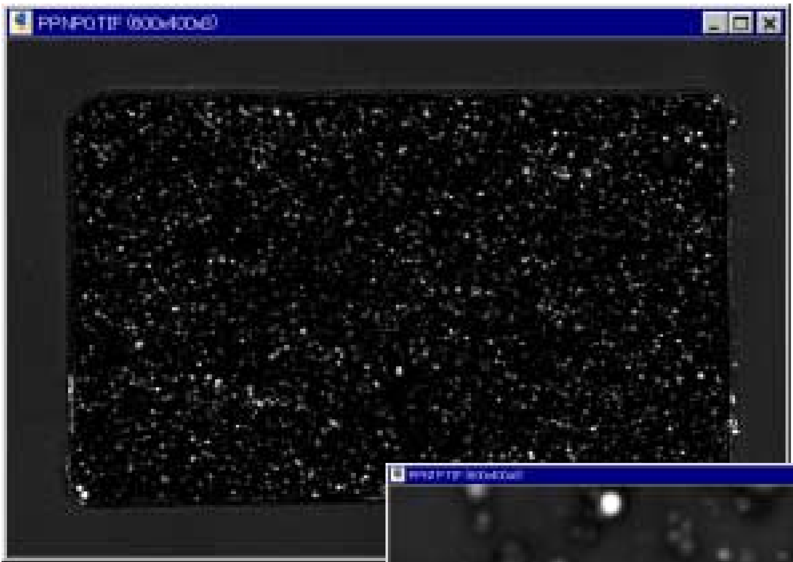


Resin with dispersed filler grains

(60mm X 40mm)

(6mm X 4mm)

Resin with cohering filler grains



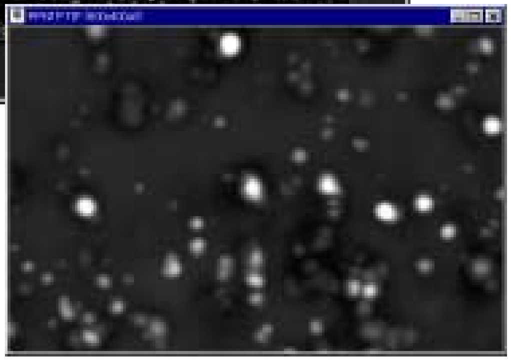


Image 16: Resin flow image (1)

When an image of injection-molded resin is made using low-frequency ultrasonic, an image that appears exactly like the resin flowing from the injection gate is obtained. It is considered that the change in temperature during injection, the change in viscosity, the change in temperature of the parts near the die and also the internal temperature result in an internal condition that differs from place to place.

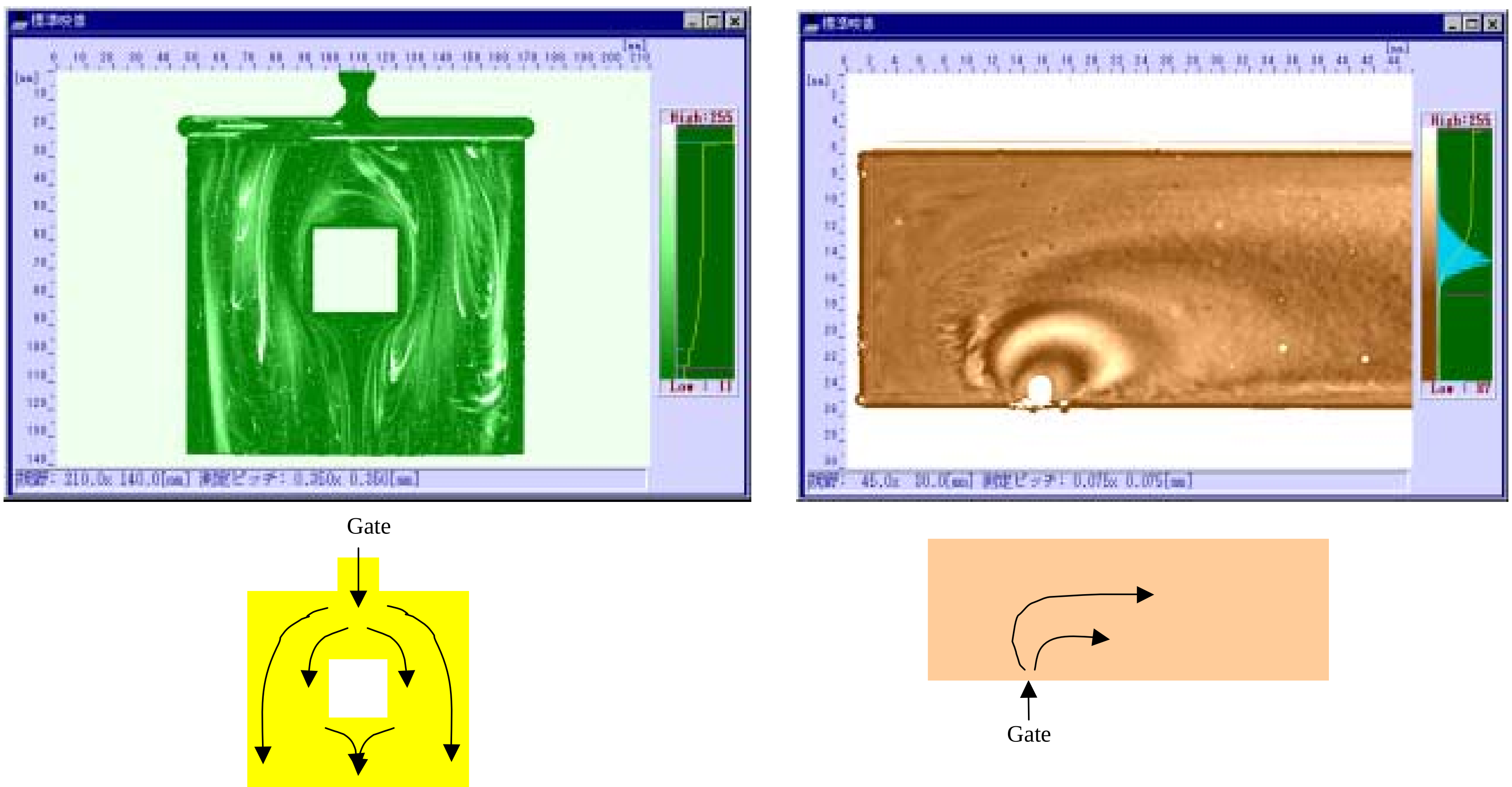
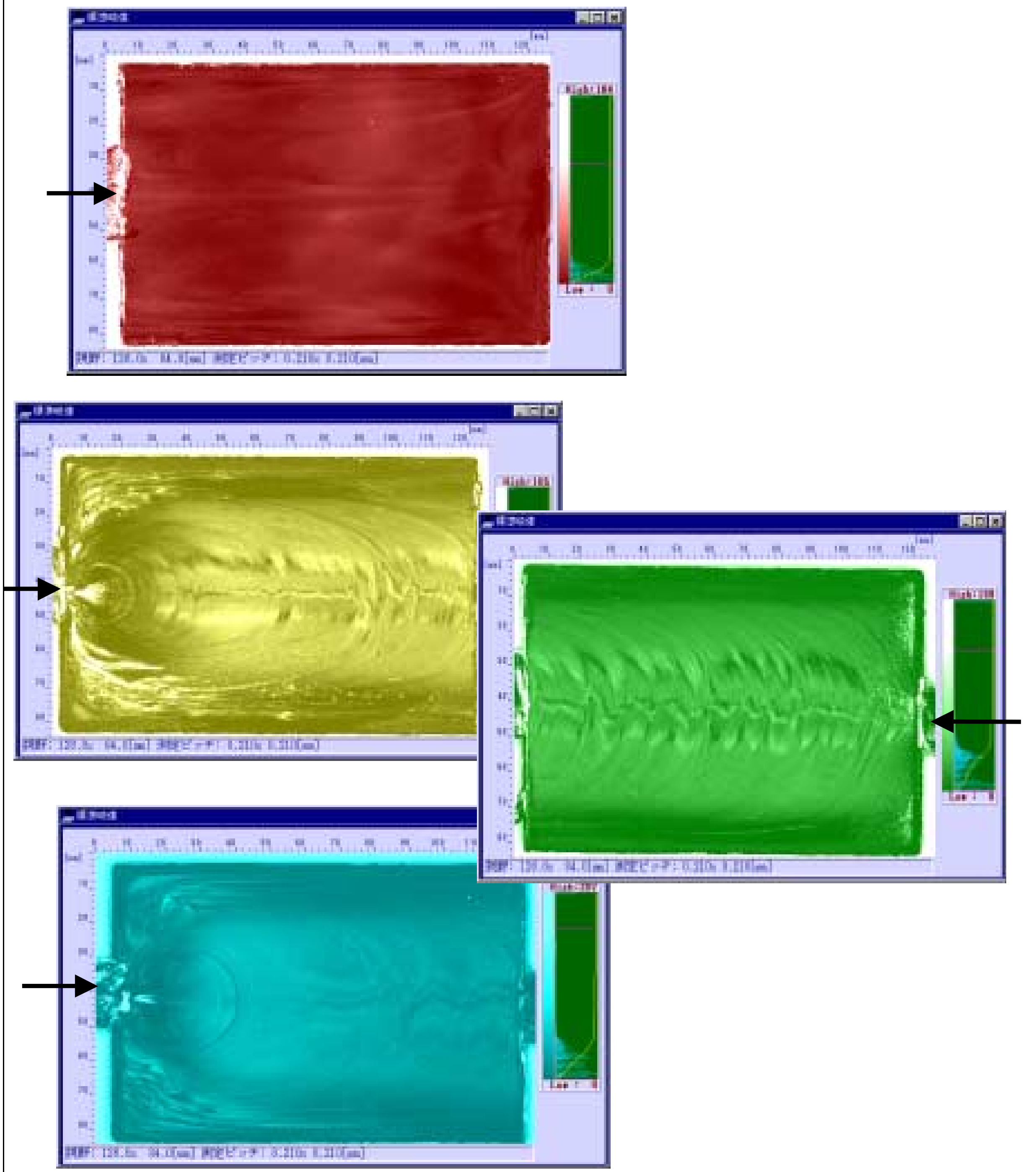


Image 17: Resin flow image (2)

This is an image of injection-molded resin. Individual gates are indicated by the arrow. Apart from the image of the top stage, various flow patterns are observed. In this case, the difference is manifest as warping at the following three points.

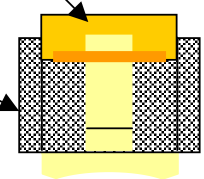


<u>Image 18: Image of cracks in a thermally sprayed film and inclusions in a steel sheet</u>

High resolution is necessary to detect cracks in an ultra-thin layer, and previously ultrasonic of about 100 MHz was required. By measuring the surface leakage waves using an ultrasonic sensor intended for detecting surface defects (DH lens method), we obtained a clear image even at 20 MHz.

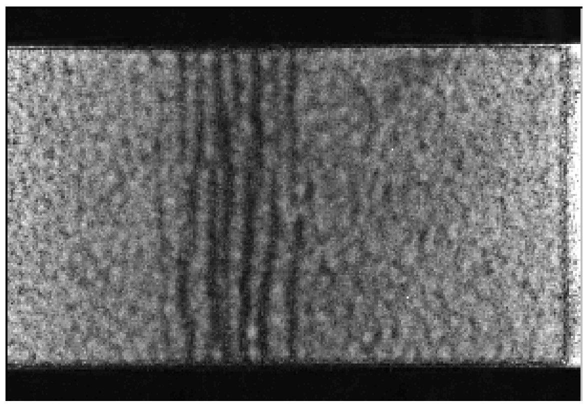
<u>DH lens method:</u>

In order to extract data from only the extreme surface layer using a leakage elastic surface wave (LSAW), we installed an acoustic lens with an incident angle that excited the LSAW on a flat type probe.
We also have a cavity acoustic lens in order to remove the anticipated vertical longitudinal wave interference.

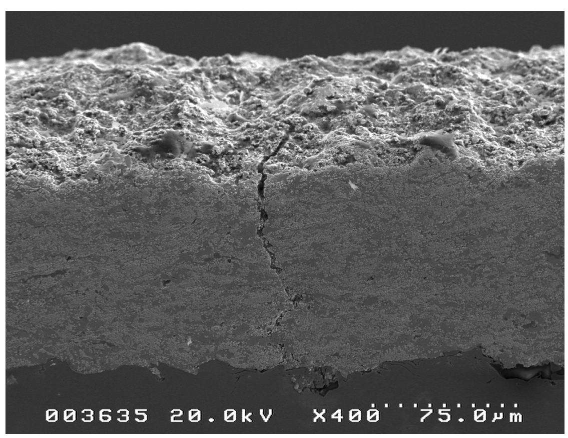


<u>Ultrasonic image of a thermally sprayed film</u>

Ultrasonic image (18mm X 12mm)

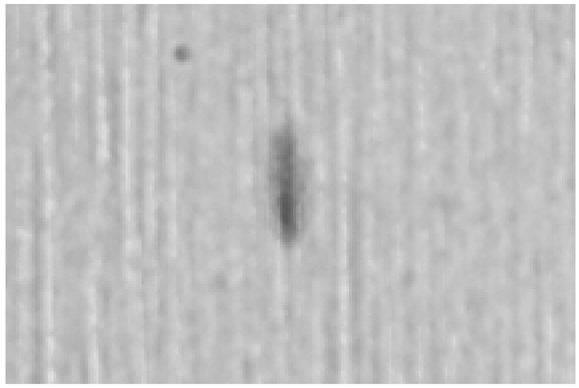


Cross section image of SEM

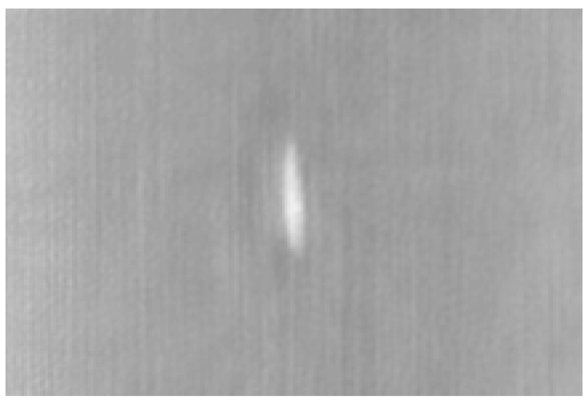


Inclusions in a steel sheet

Ultrasonic image (Usual method - 100MH)



DH lens method (20MHz)



Cross section image using SEM