

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



ERA23FA047

G-1000 SD CARD

Specialist's Factual Report

July 24, 2023

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A. ACCIDENT

Location: Alpharetta, GA
Date: October 31, 2022
Time: 1303 EDT
Airplane: HAWKER BEECHCRAFT G58

B. G-1000 SD CARD SPECIALIST

Specialist Joseph Gregor
Electronic
Engineer
National Transportation Safety Board (NTSB)

C. DETAILS OF THE INVESTIGATION

A group was not convened.

The NTSB Vehicle Recorder Division received the following electronic device:

Recorder Manufacturer/Model: SanDisk SD Card
Part Number: SHDC 8GB
Recorder Serial Number: 811031916095D

1.0 SanDisk SD Card Description

The Garmin G1000 Integrated Flight Deck is a collection of multiple avionics units which include flight displays, air data computers, attitude/heading reference system (AHRS), communications and other systems. A typical installation includes a primary flight display (PFD) and a multi-function display (MFD). Each display includes two secure digital (SD) card slots, an upper and a lower slot. The lower SD card slot is used by the system for software updates and various databases.

Depending on the installed software, the display unit can include a data logging feature. The data logging feature must be enabled by the aircraft operator. If the data logging feature is available and enabled, a SD card must be installed in the upper slot of the MFD. Depending on the airframe and engine combination as many as 64 parameters can be stored at a rate of one sample per second (1Hz). According to the manufacturer of the display unit, one flight hour generates approximately 2-megabytes (MB) of data. The SD card typically used is 2-gigabyte (GB) in size and can store over 1,000 flight hours of data.

1.1 SanDisk SD Card Data Recovery

The SD Card was damaged in the event. Preliminary X-Ray analysis showed no clear indication of catastrophic damage. But, attempts to power the SD card and read out stored data were unsuccessful. Anomalous heating of the SD Card when under power indicated the presence of an electronic problem not discernable by in-house optical or X-Ray analysis. The SD Card was sent to a university-based failure electronics laboratory for more extensive testing using tools and techniques not available in-house to diagnose the nature of the internal damage. A report was received indicating possible damage, but with inconclusive evidence concerning non-remedial damage to the die.

The SD Card was sent to a third-party lab to attempt a forensic data recovery using advanced tools and techniques geared toward damaged electronic mass-memory drives. All techniques available to recover data from the SD Card were exhausted by this lab and it was returned to the NTSB recorder laboratory.

No data was recovered from the SD Card.



Figure 1. SD Card as recovered from the accident site.

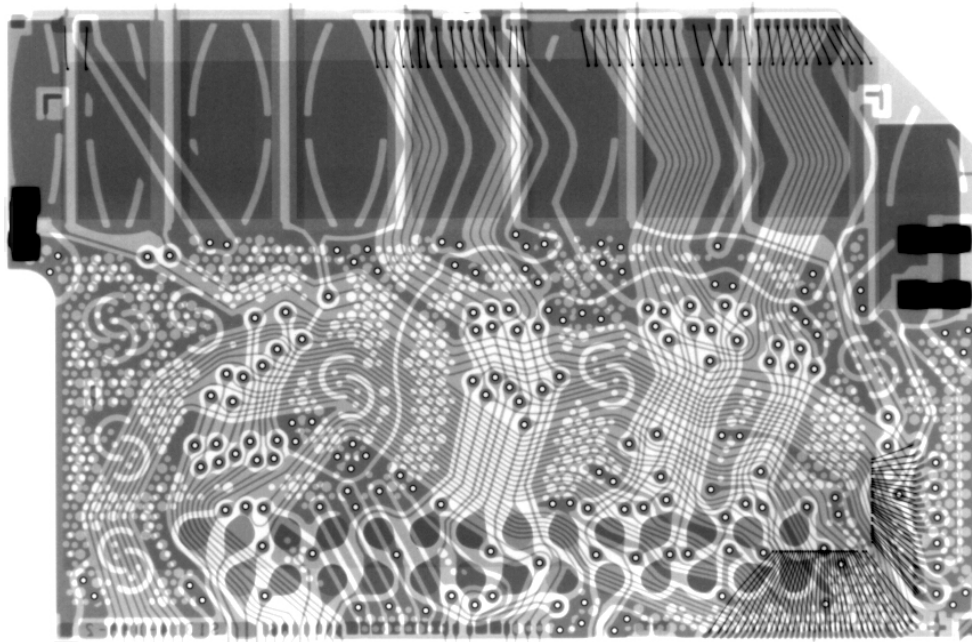


Figure 2. X-Ray image of SD Card

D. FIGURES AND TABULAR DATA

The detailed results of the Integrated Electronics Engineering Center (IEEC) at Binghamton University failure analysis report are provided in Appendix A.

Submitted by:

Joseph A Gregor
Electronic Engineer

APPENDIX A

Binghamton University failure analysis report

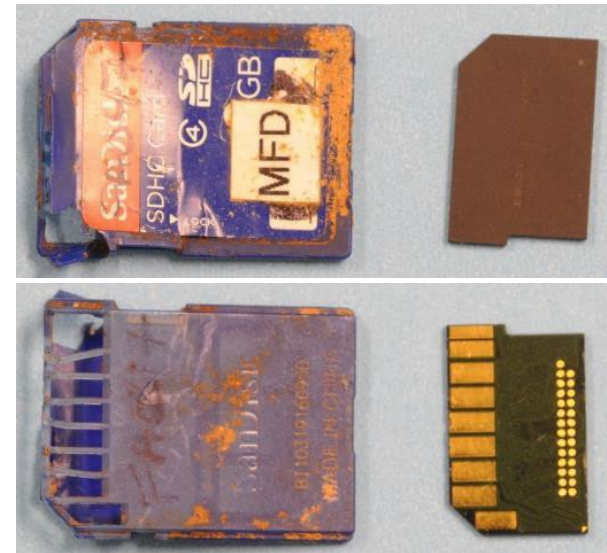
ERA23FA047 – Failure Analysis Report

S.R. Cain, A. Sharma
Prepare for the NTSB
Initial Report 2/8/2023
Revised 2/14/2023

Overview

- **One device received for nondestructive analysis**
 - ID: ERA23FA047
 - Case and module were in separate packages
- **Key personnel**
 - Dr. Stephen Cain
 - Dr. Anju Sharma
- **Techniques**
 - Optical microscopy
 - X-ray analysis (Cu filter to harden x-rays)
 - CSAM (50, 100 and 150 MHz transducers) *in the echo and through scan modes*
- **Results from optical inspection**
 - Device had no observable thermal damage
 - Mechanical damage was confined to the periphery, where some internal circuitry had been exposed
 - Inconclusive as to whether the damage broke circuit lines
- **Result for X-ray analysis**
 - All wirebonds were intact and well shaped
 - No evidence of discontinuity in the wires
 - Circuit lines in the damaged areas appeared to be intact
 - Inconclusive as to whether damage caused interplane short circuits at the periphery of the device – *CT scan results showed no such possibility.*
 - *Proximity of wirebonds to the mechanical damaged are, may have caused some to lift-off; separation is usually too small to detect with non-destructive techniques.*

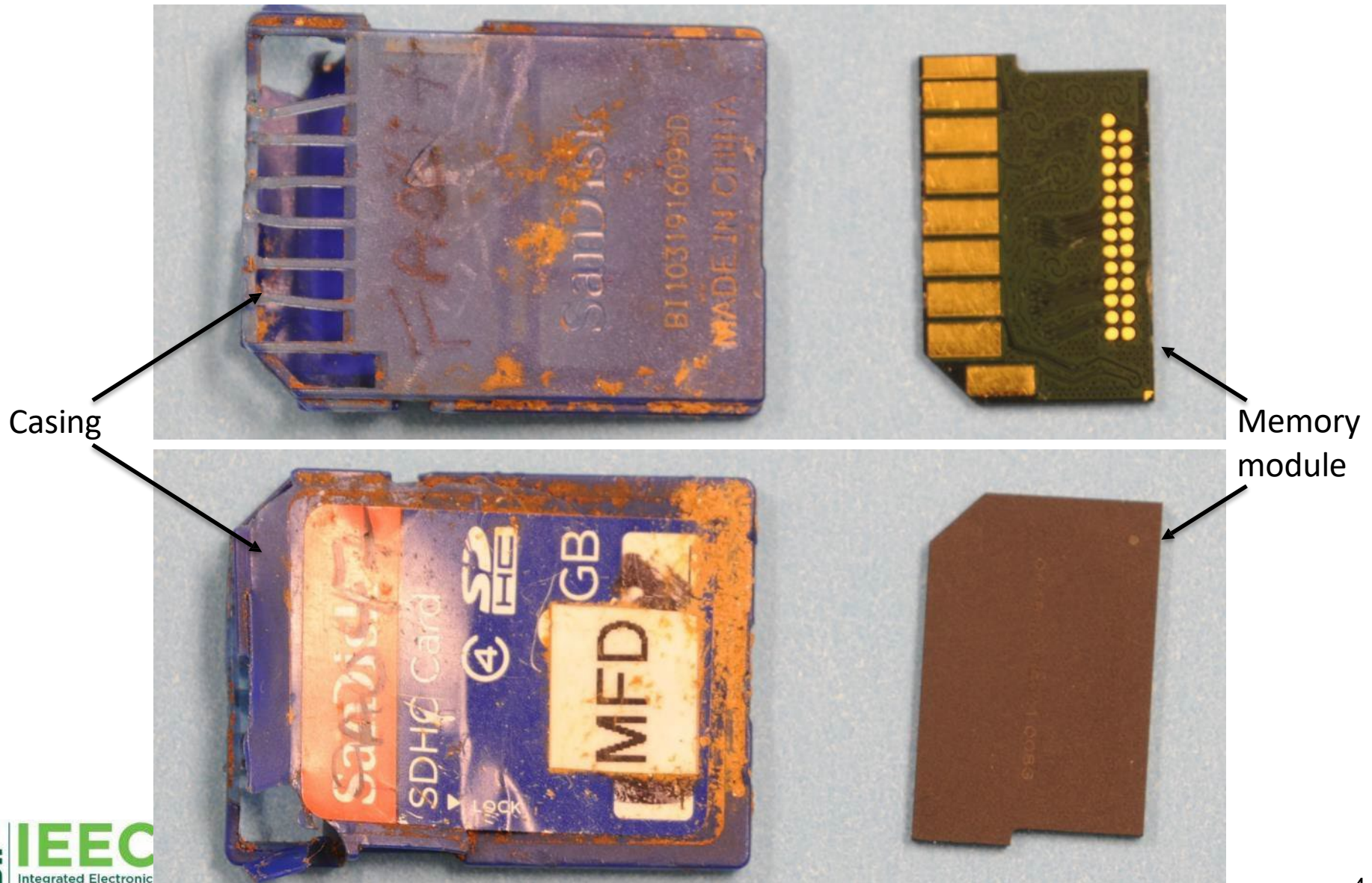
- **Results of CSAM analysis**
 - Two chips were observed in a stacked configuration
 - A very subtle line was observed on the larger, lower chip – this might indicate a chip crack – *not seen in the follow-up C-SAM testing. Suggest possible anomaly in the mold.*
 - The bottom side of the lower chip showed a several streaks, which may be due either to chip cracking, or to nonuniformities in the adhesive.
 - *Follow-up C-SAM in the through scan mode showed delaminations in the die attach (possibly caused due to mechanical damage)*
 - Inconclusive as to whether the chip is cracked
- **Disposition:**
 - *Several areas exhibit sufficient damage to have caused functional failure. This includes possibility of die cracks and/or lift-off of the wire bonds from mechanical damage.*



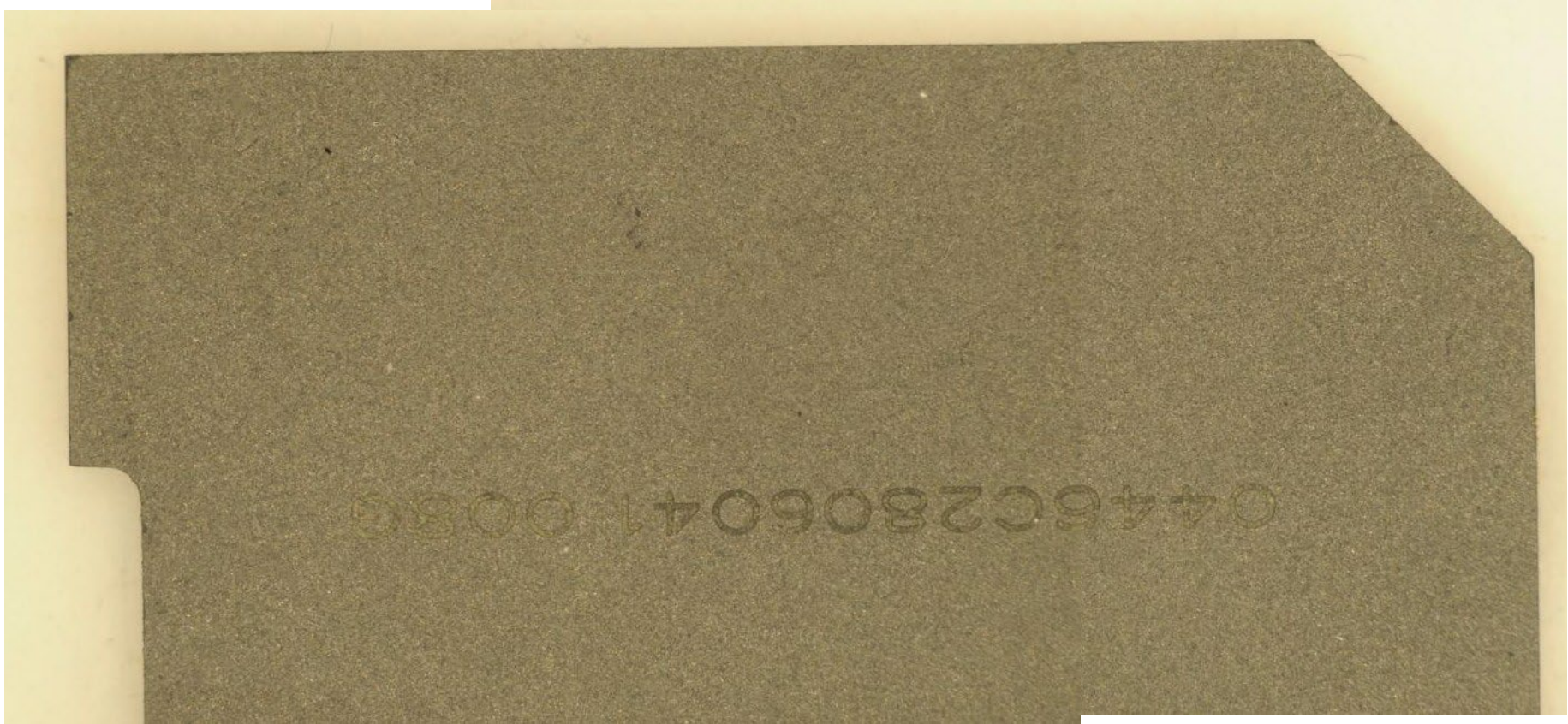
Section 1

OPTICAL IMAGES

As Received



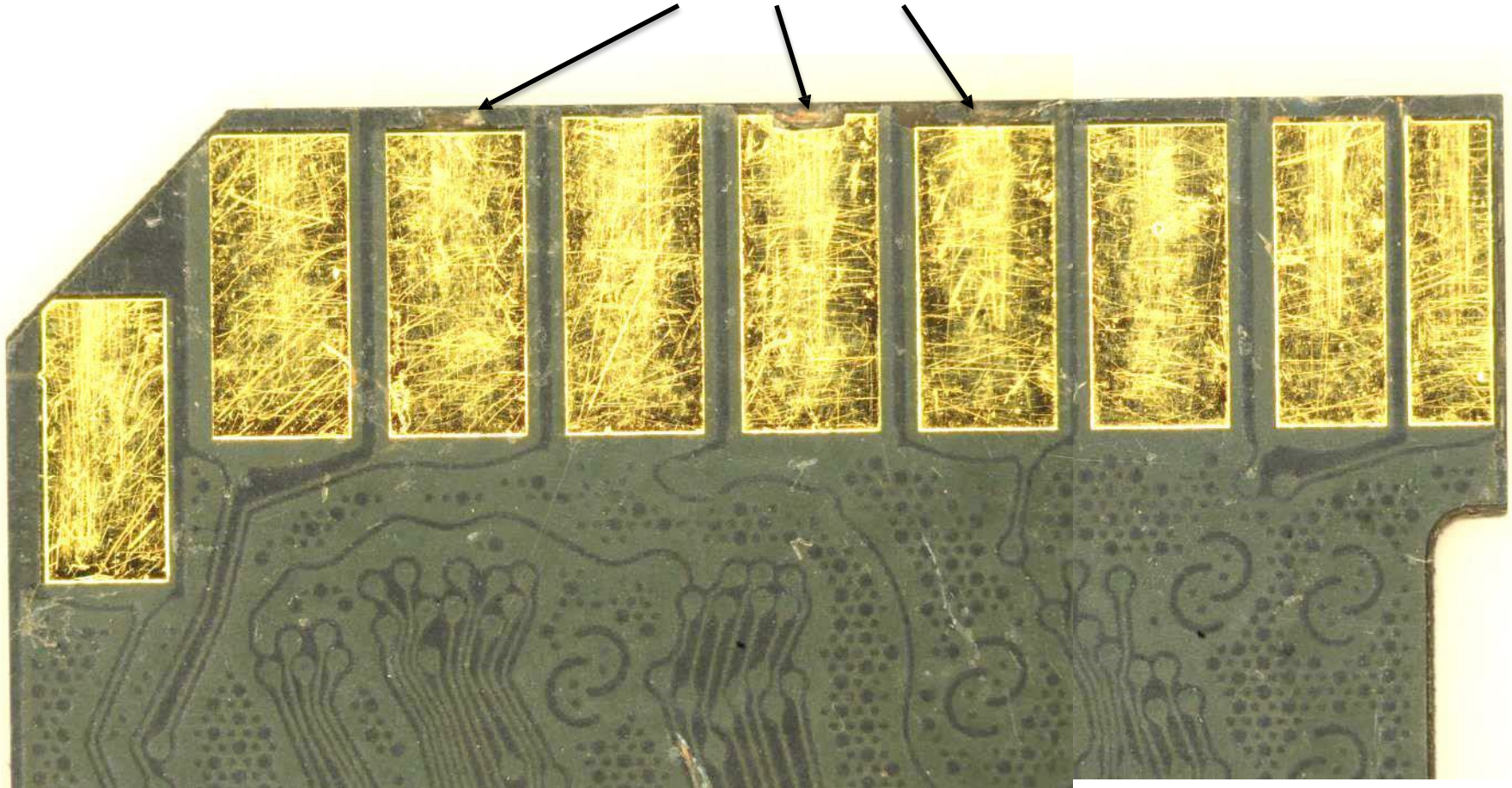
Gold Contact Edge (Top Side, Stitched Image)



No evidence of thermal or mechanical damage

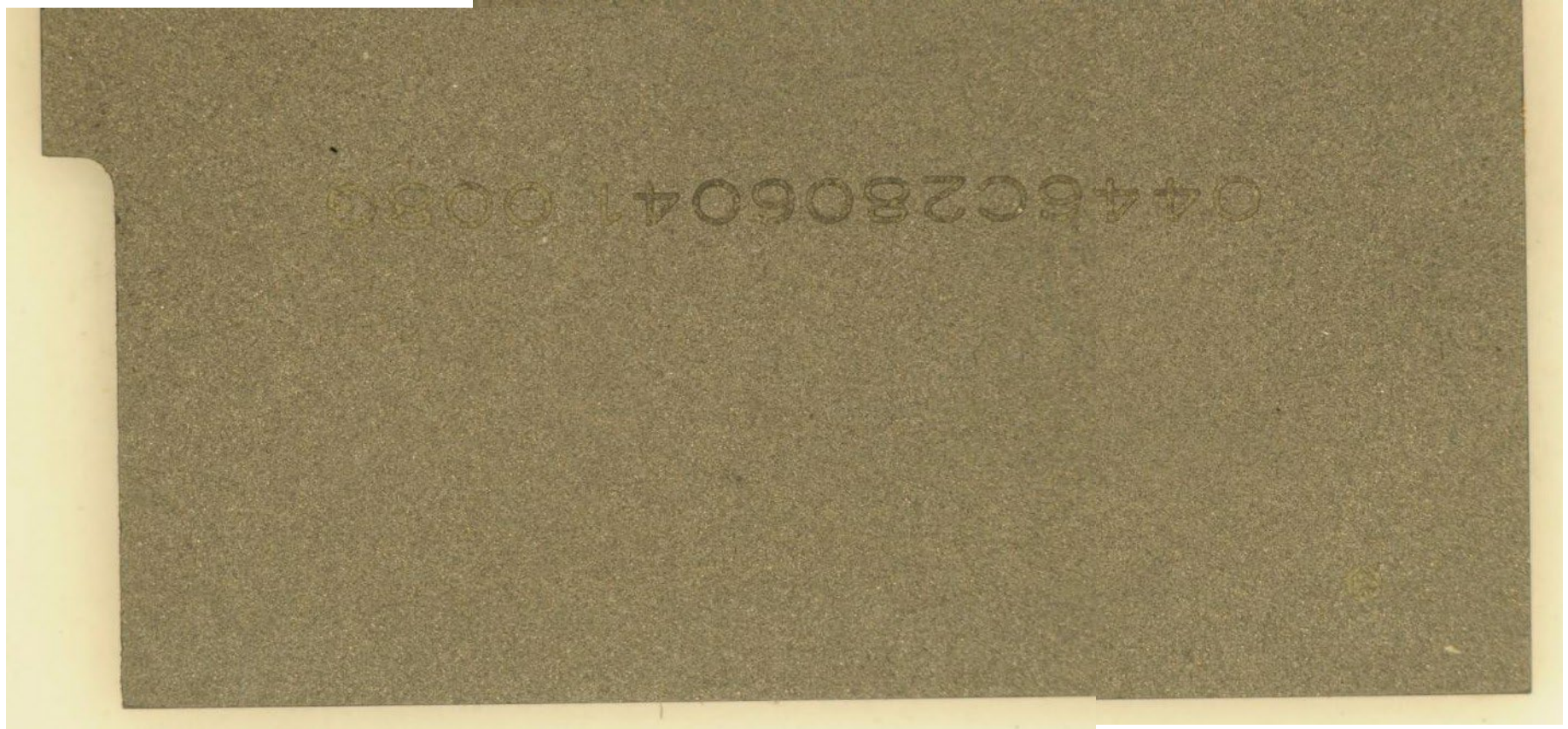
Gold Contact Edge (Bottom Side, Stitched Image)

Mechanical Damage



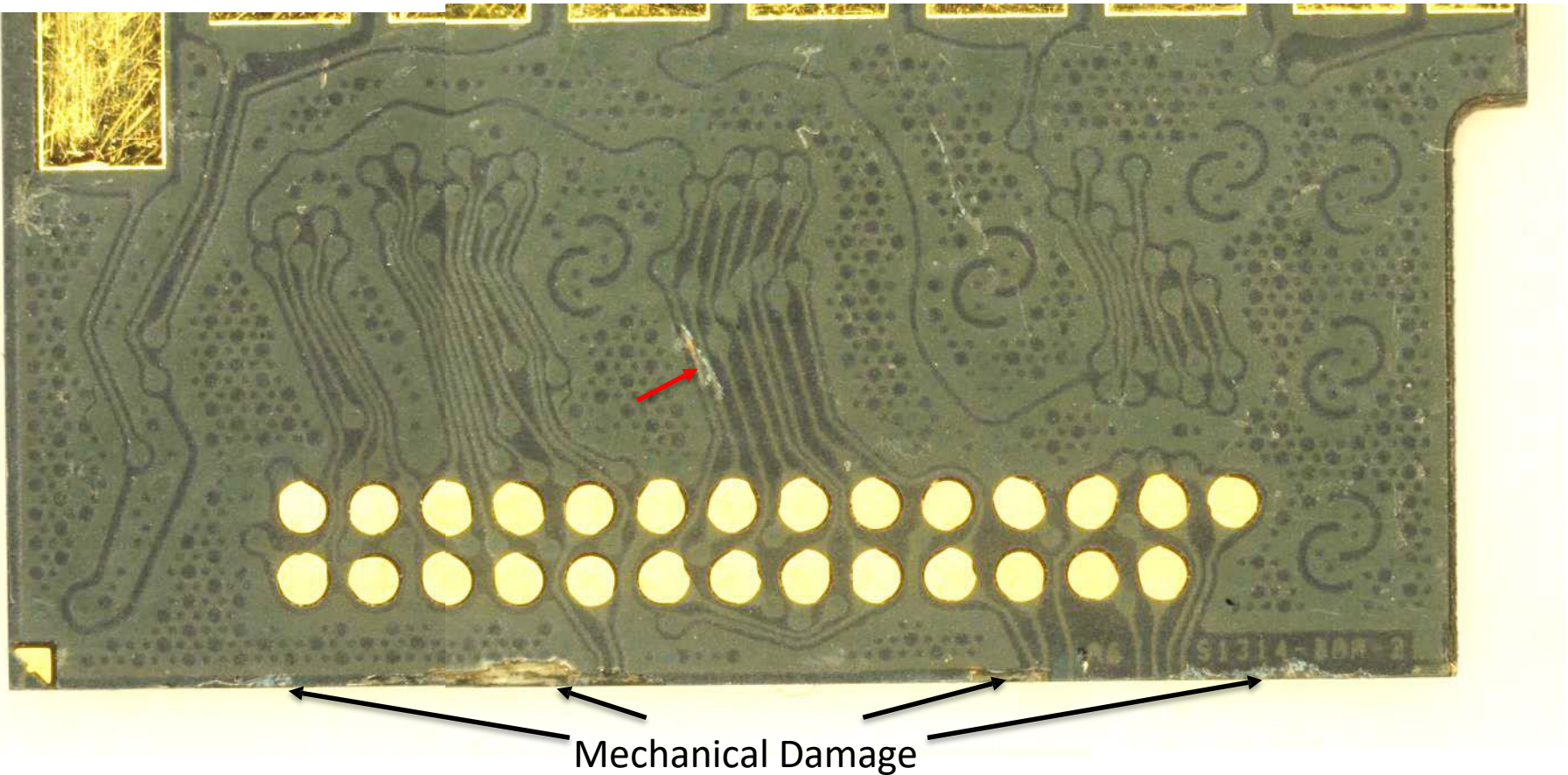
- Damage at the edges
- Visible (near surface) circuitry at the interior is intact

Back Edge (Top Side, Stitched Image)



No evidence of thermal or mechanical damage

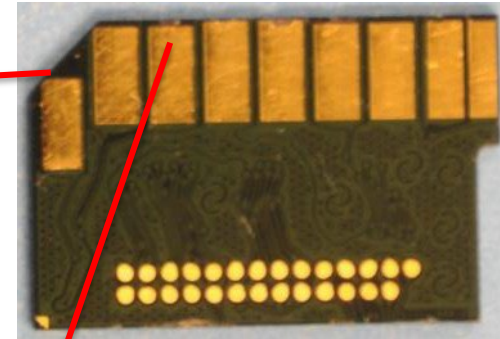
Back Edge (Bottom Side, Stitched Image)



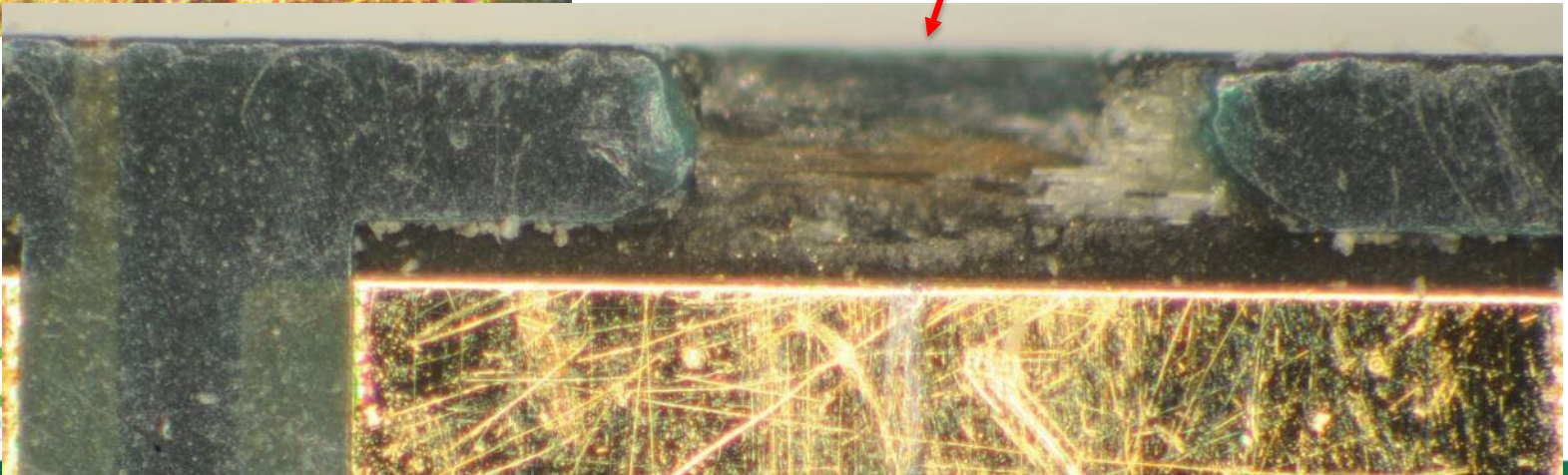
- Mechanical damage at the edges
- Exposed circuit line in the interior (red arrow) that apparently is still connected
- All other visible (near surface) lines appear to be intact

Higher Mag. View of the Contact Side Peripheral Damage

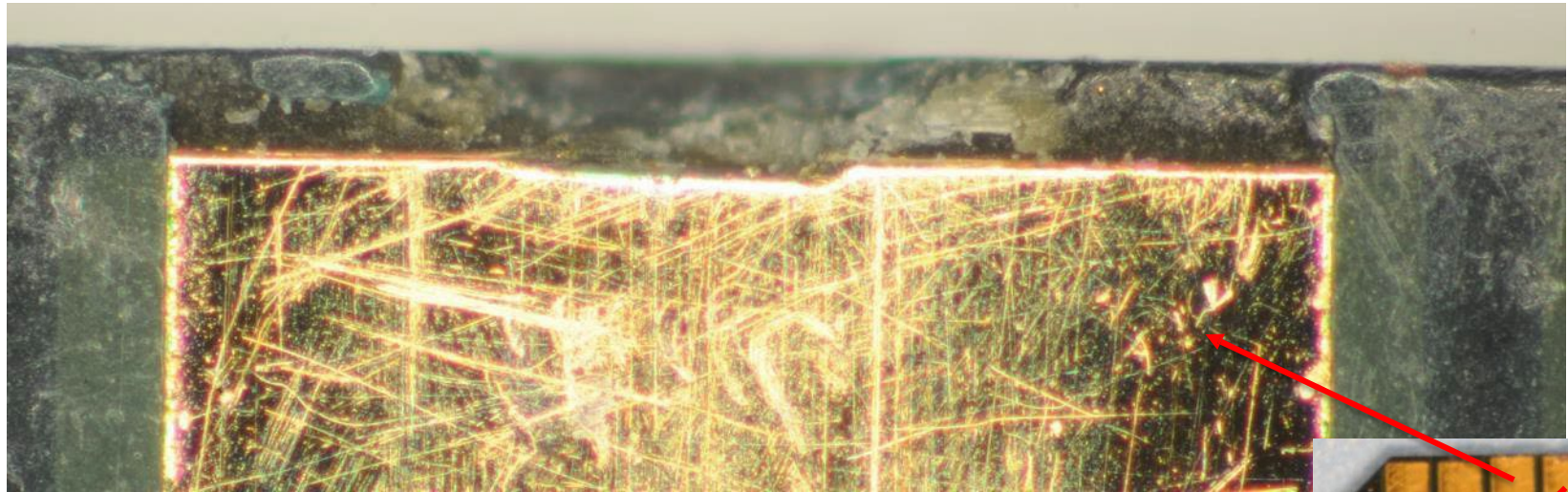
Laminate crack indicates mechanical stress, but there is no (visible) circuitry here



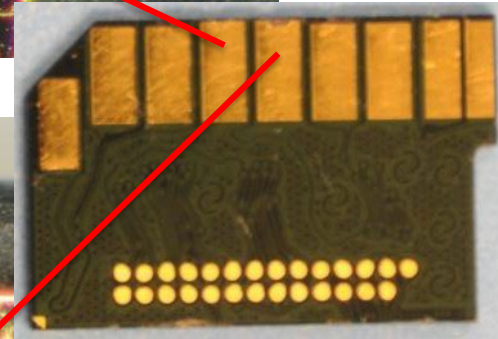
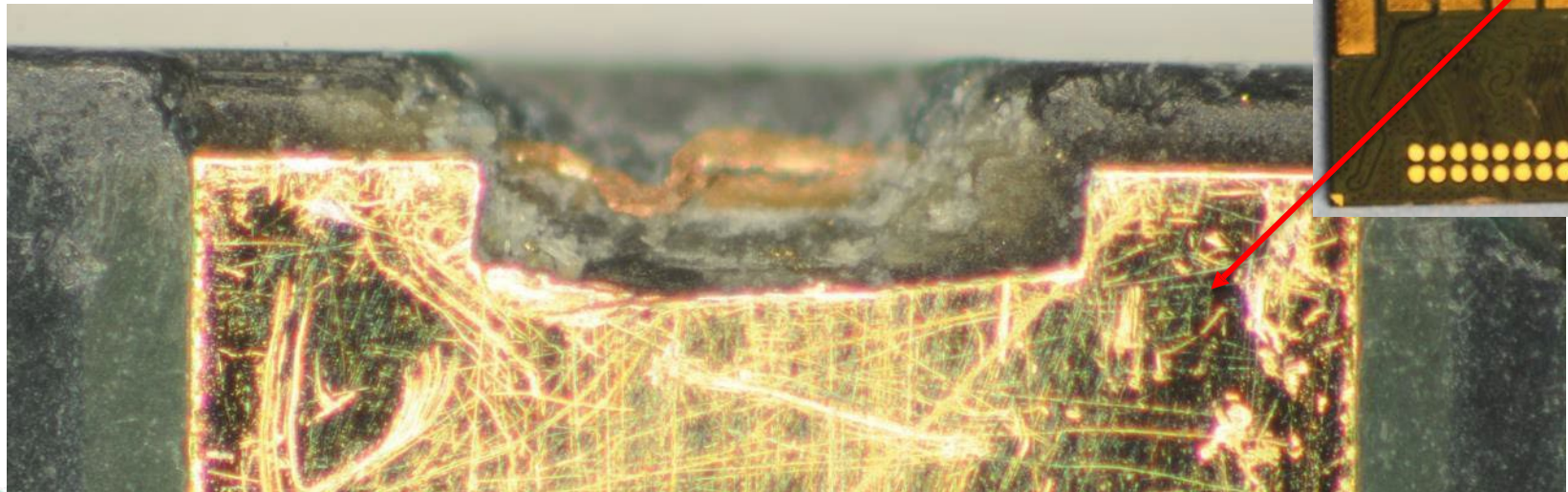
Damage does not appear to be in an area where there is circuitry



Higher Mag. View of Contact Side Peripheral Damage

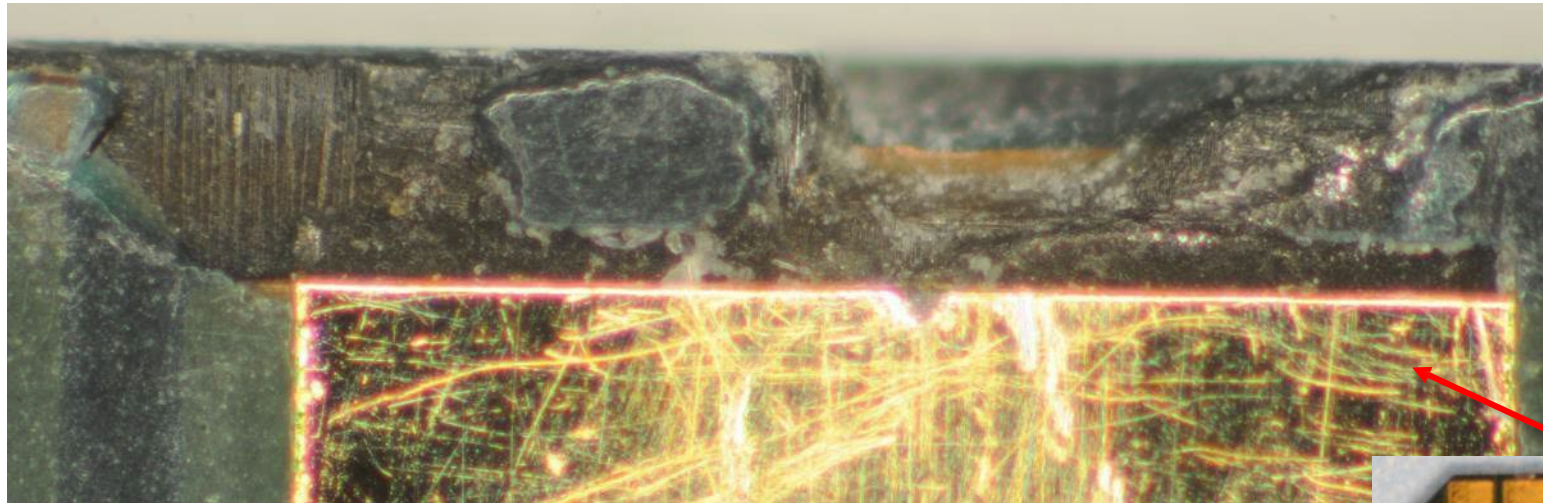


Damage to
solder mask
only

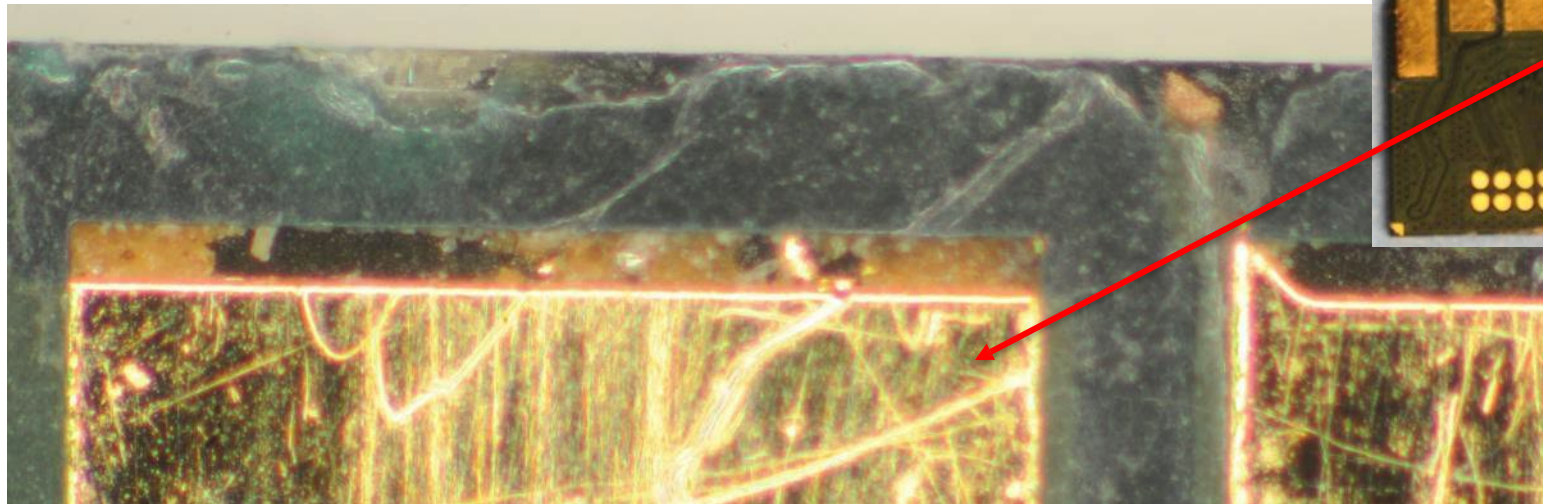


Exposed
circuit
line(s);
possibly a
short or
discontinuity

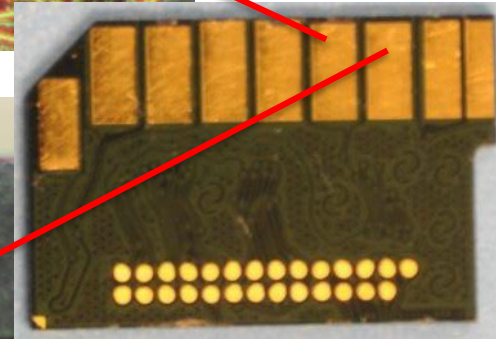
Higher Mag. View of Contact Side Peripheral Damage



Exposed circuit line, but no evident discontinuity



No apparent damage to circuit lines

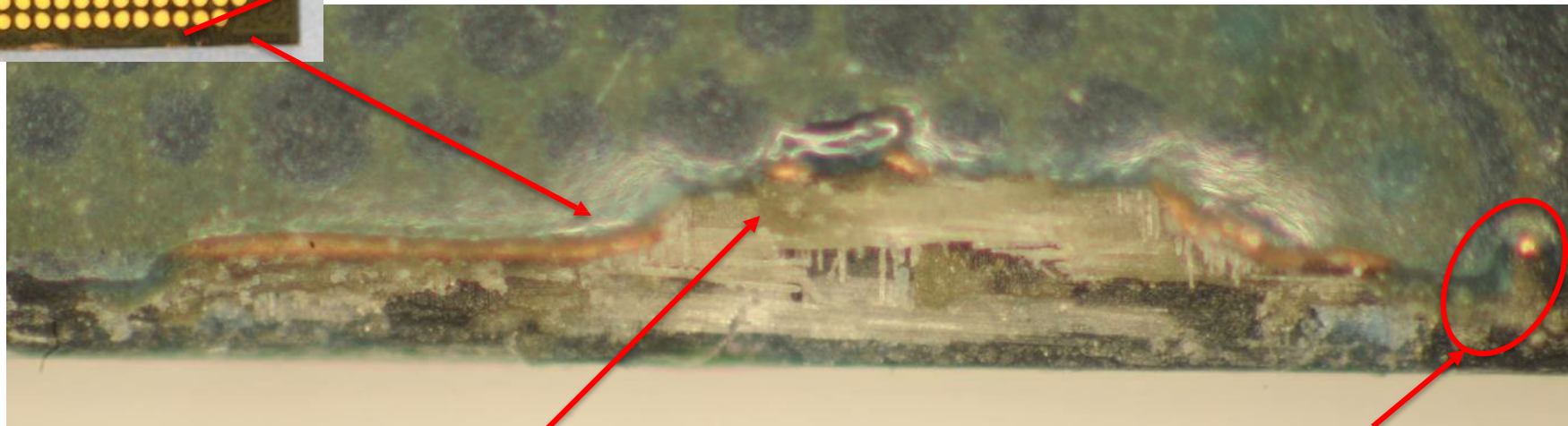
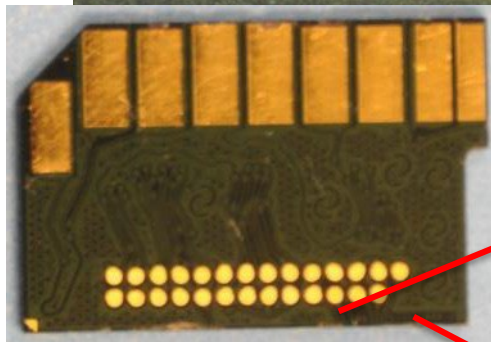


Higher Mag. View of Back Edge Peripheral Damage

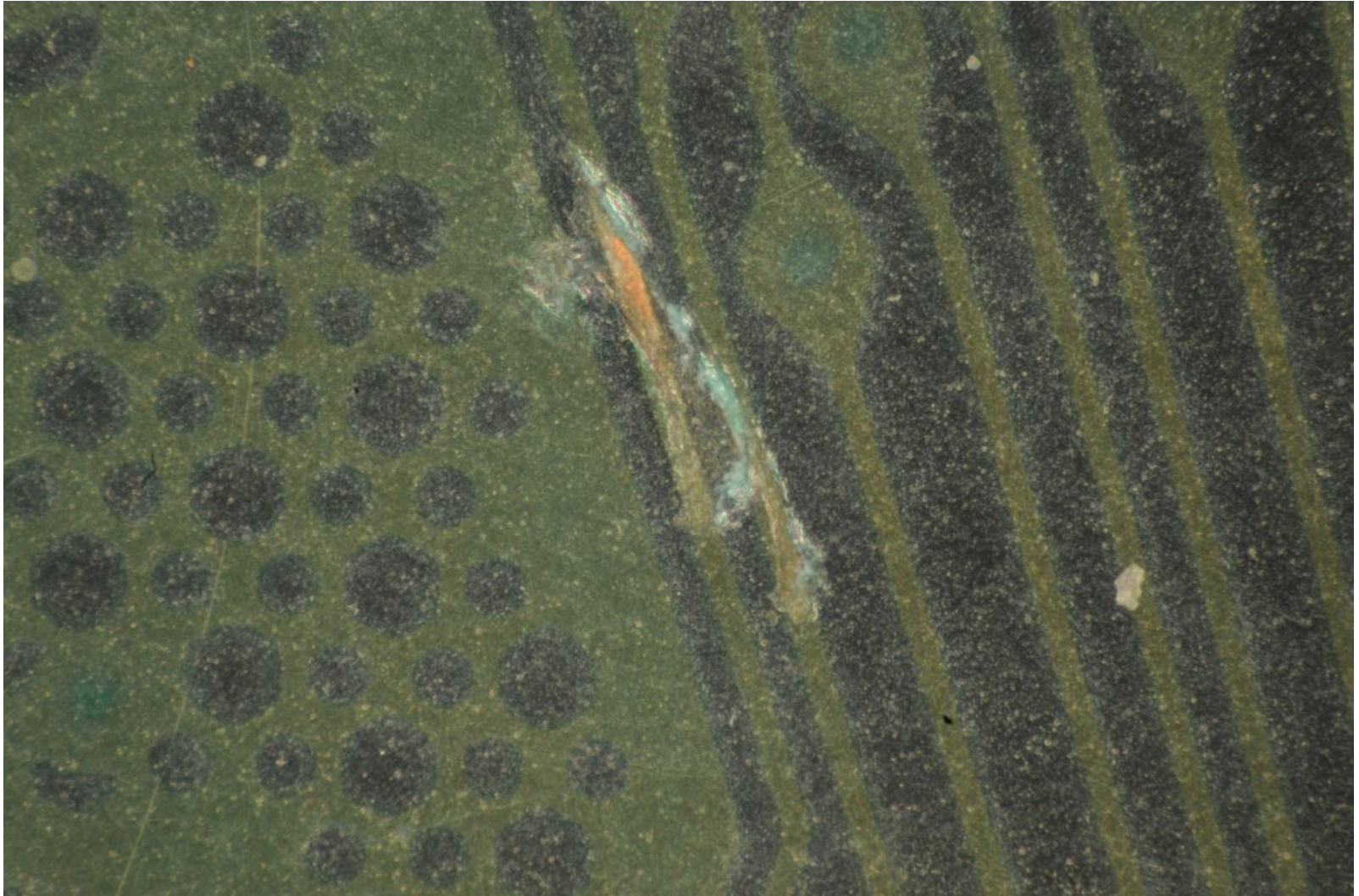
Exposed plating bus bars (yellow arrows), does not affect circuitry

Exposed power (or ground) plane, and exposed plating bus bars, does not affect circuitry

Higher Mag. View of Back Edge Peripheral Damage

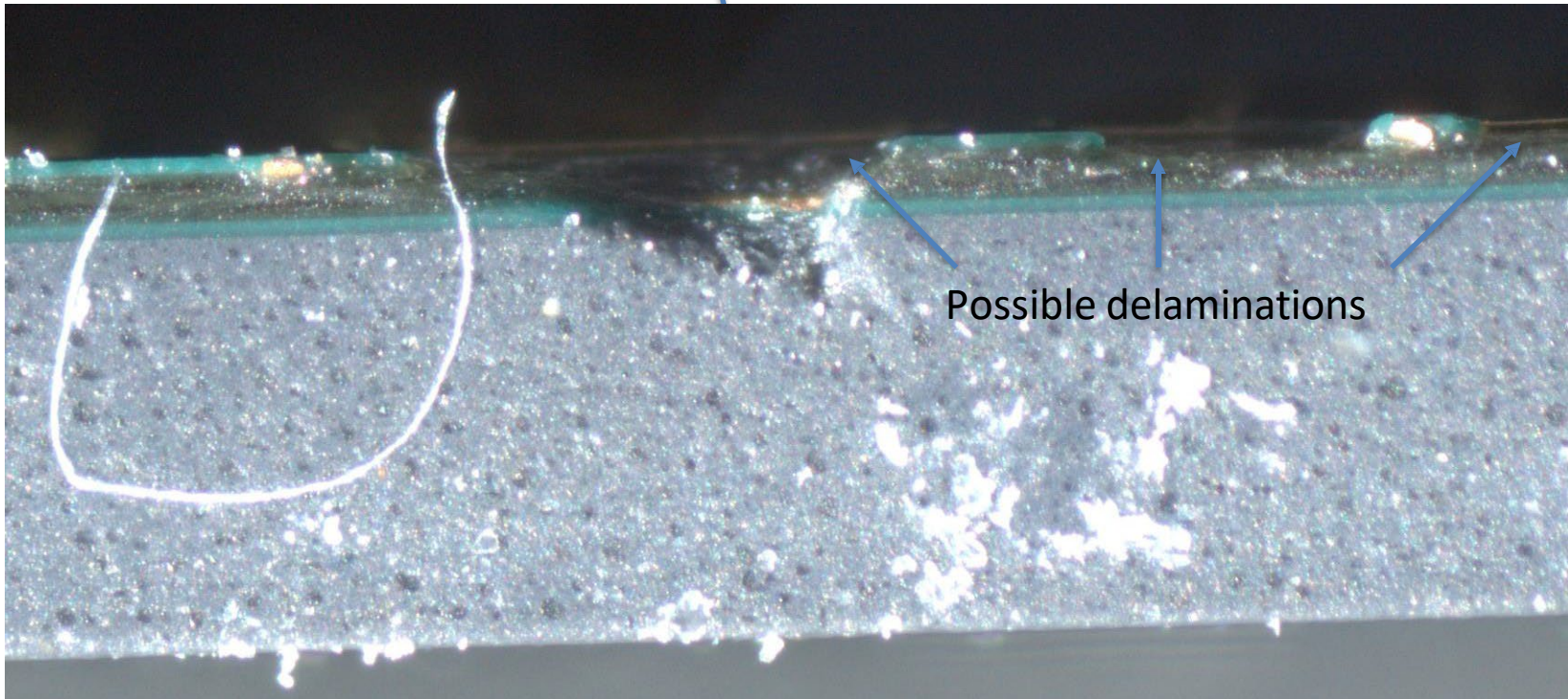
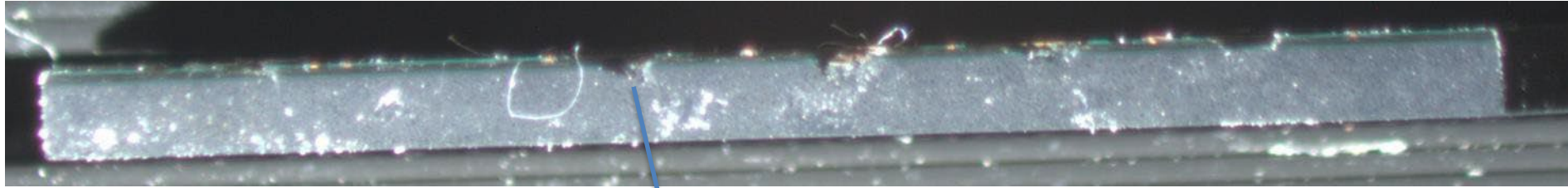


Zoomed View of Surface Damage on the Interior

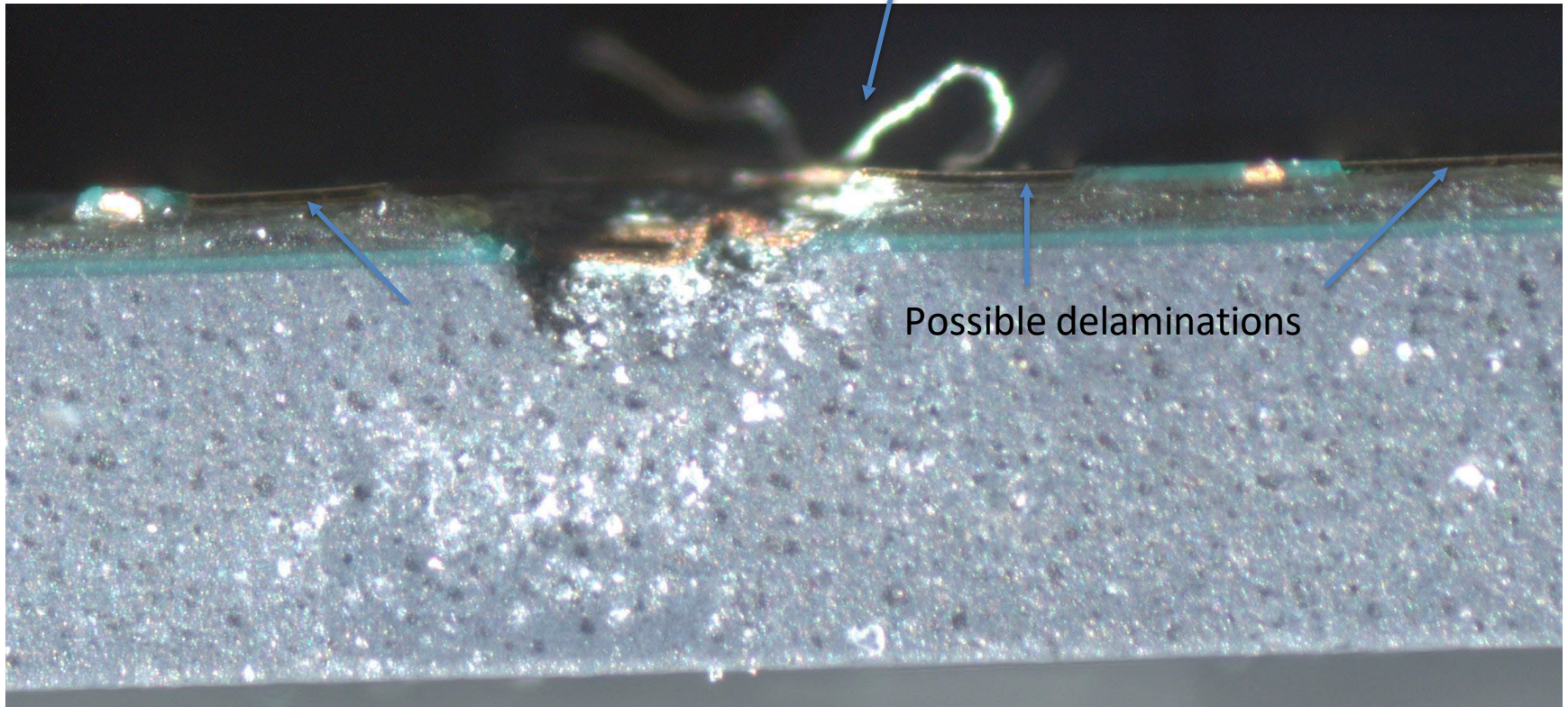
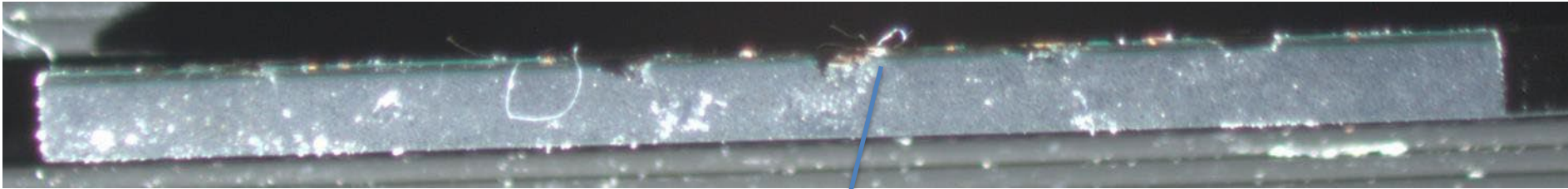


Solder mask is scratched, but the circuit line is intact

Edge view of the damaged substrate

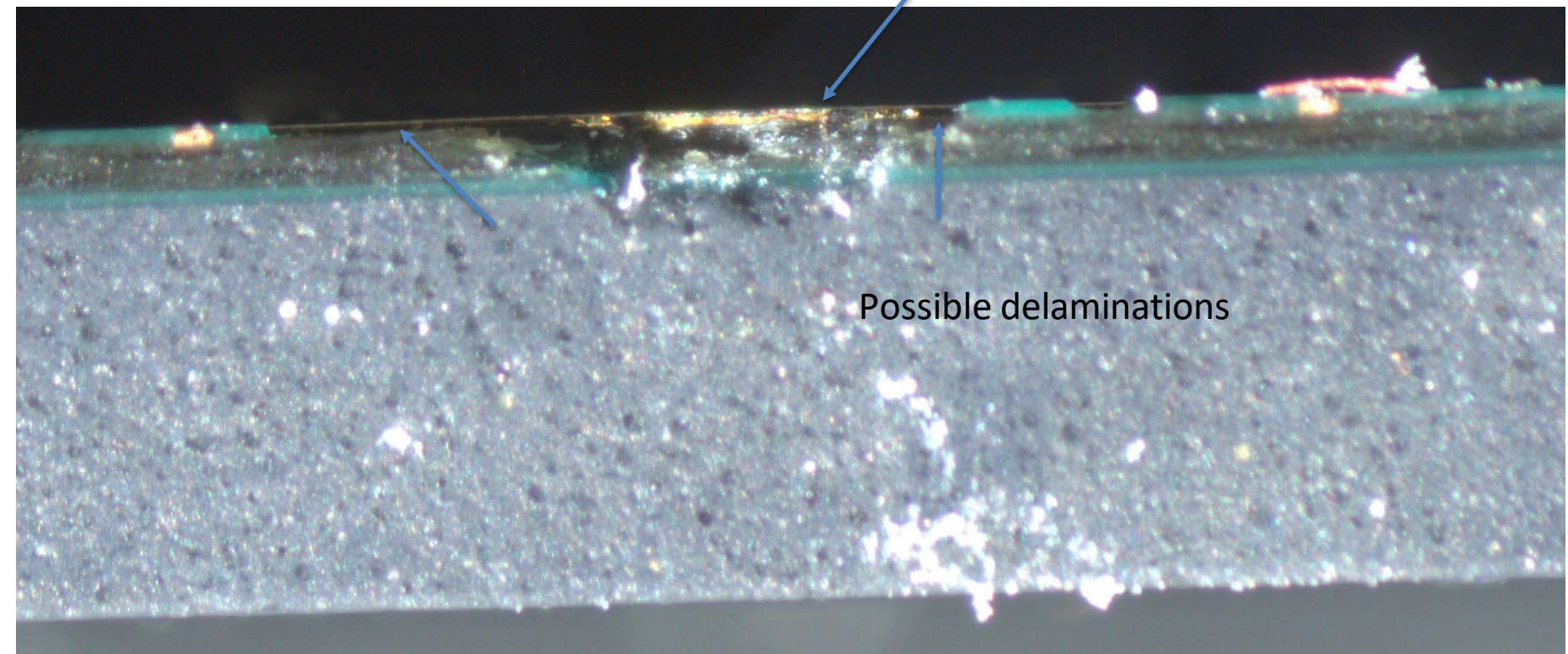
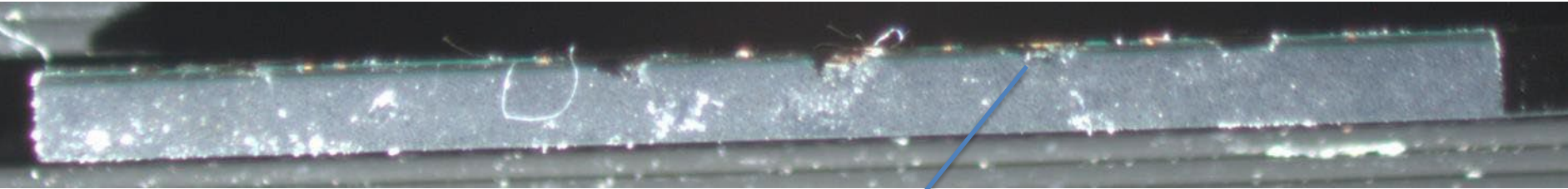


Edge view



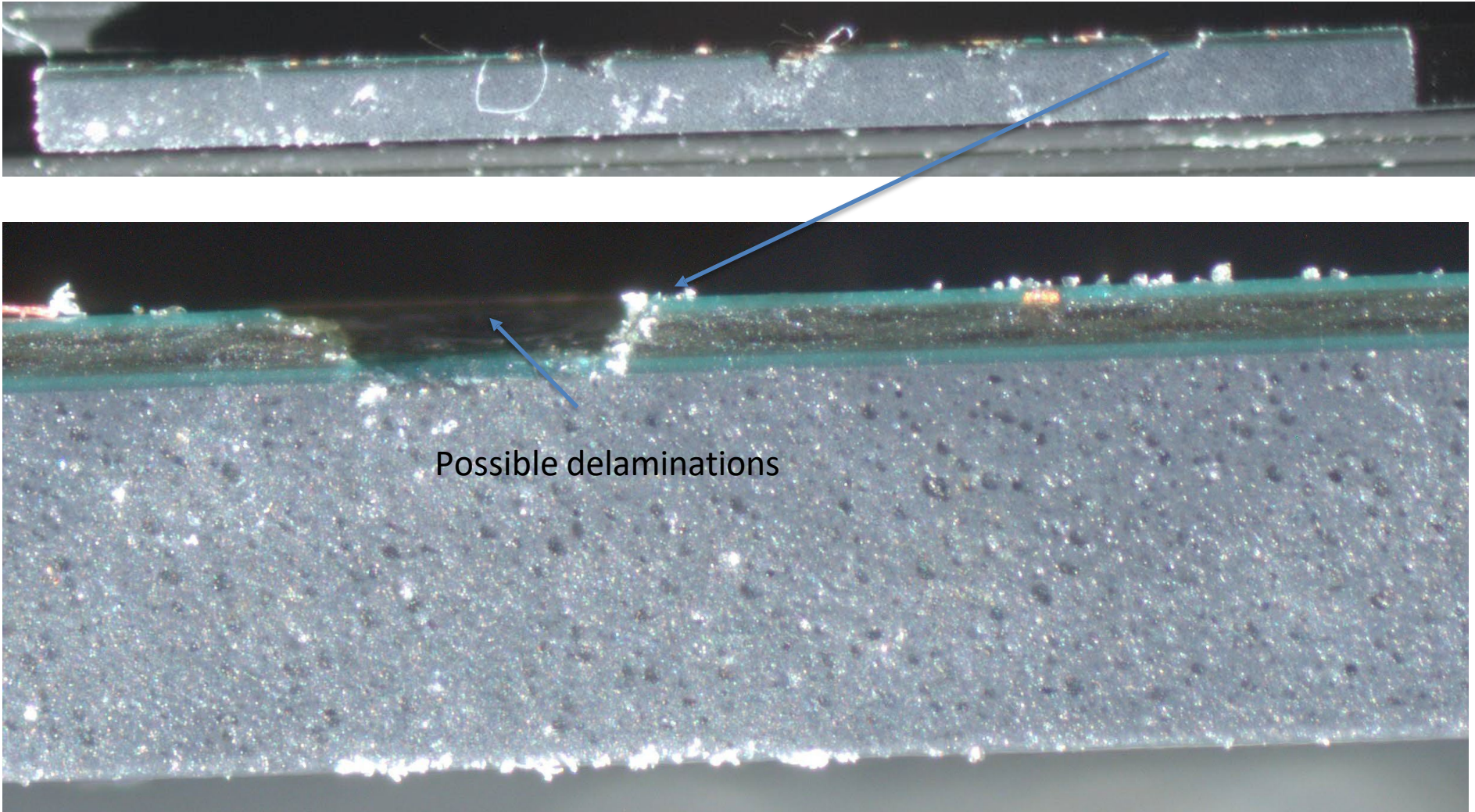
Possible delaminations

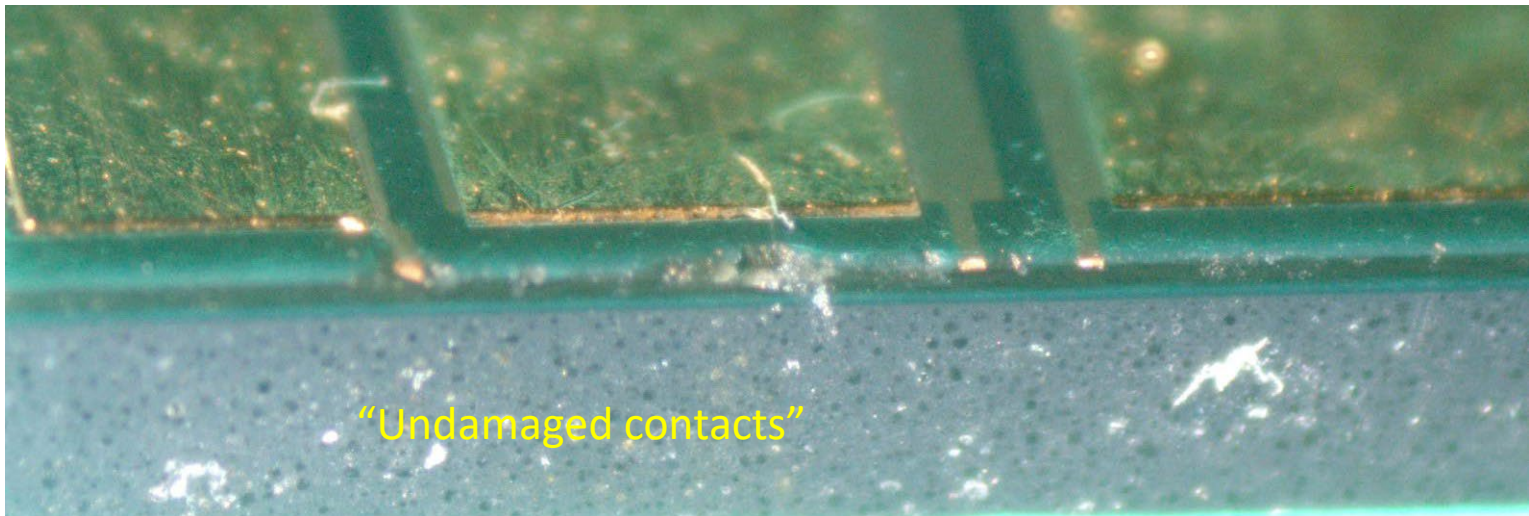
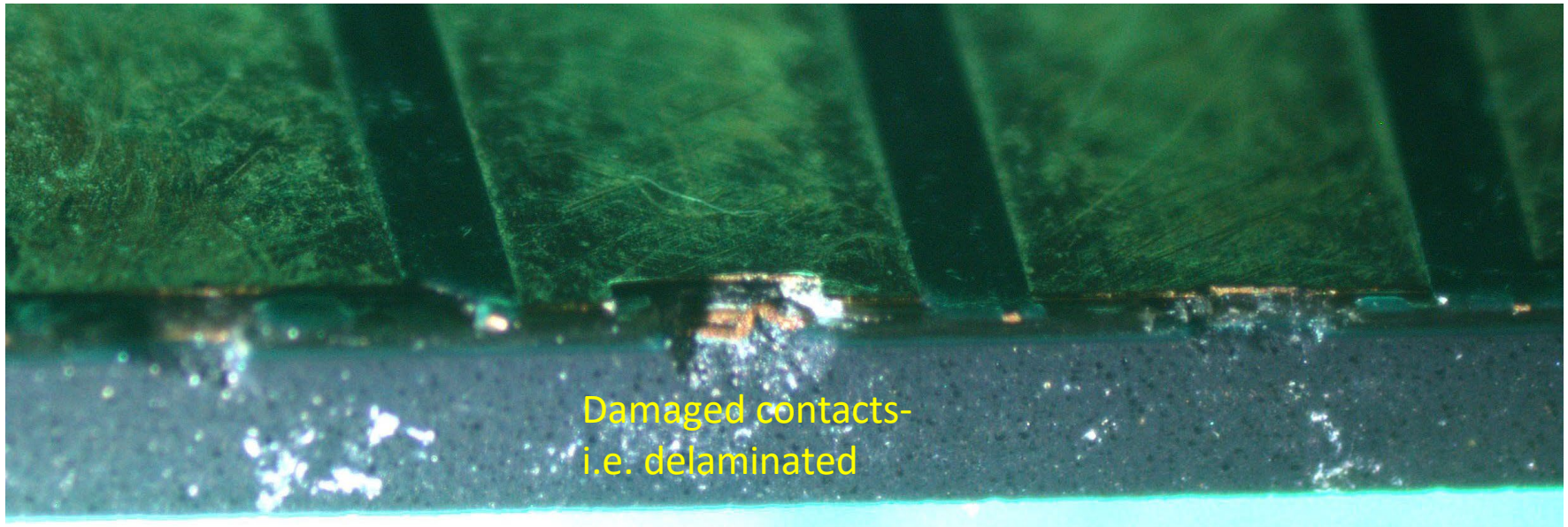
Edge view



Possible delaminations

Edge view



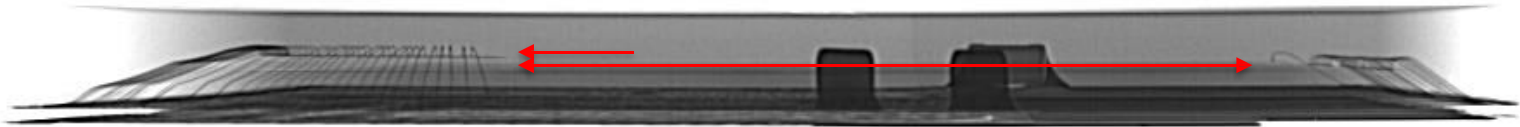


Section 2

2D X-RAY ANALYSIS

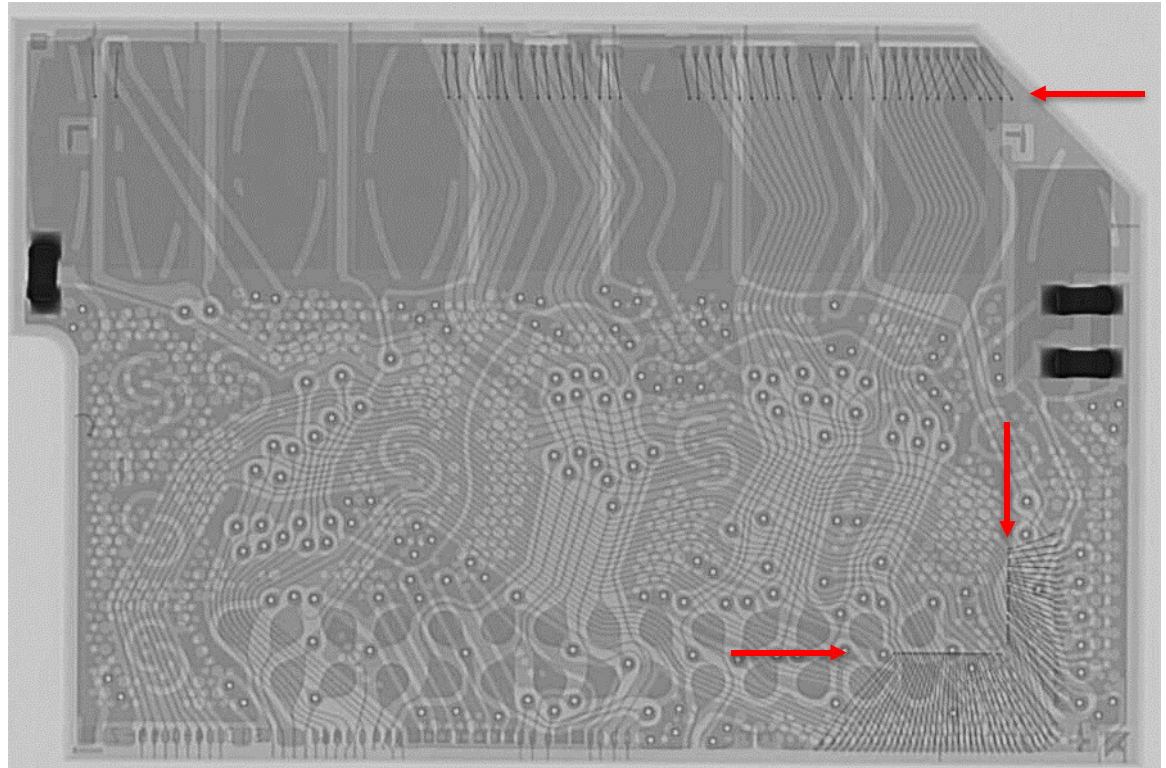
Configuration of the Module

Edge view shows two layers of chips (red arrows)

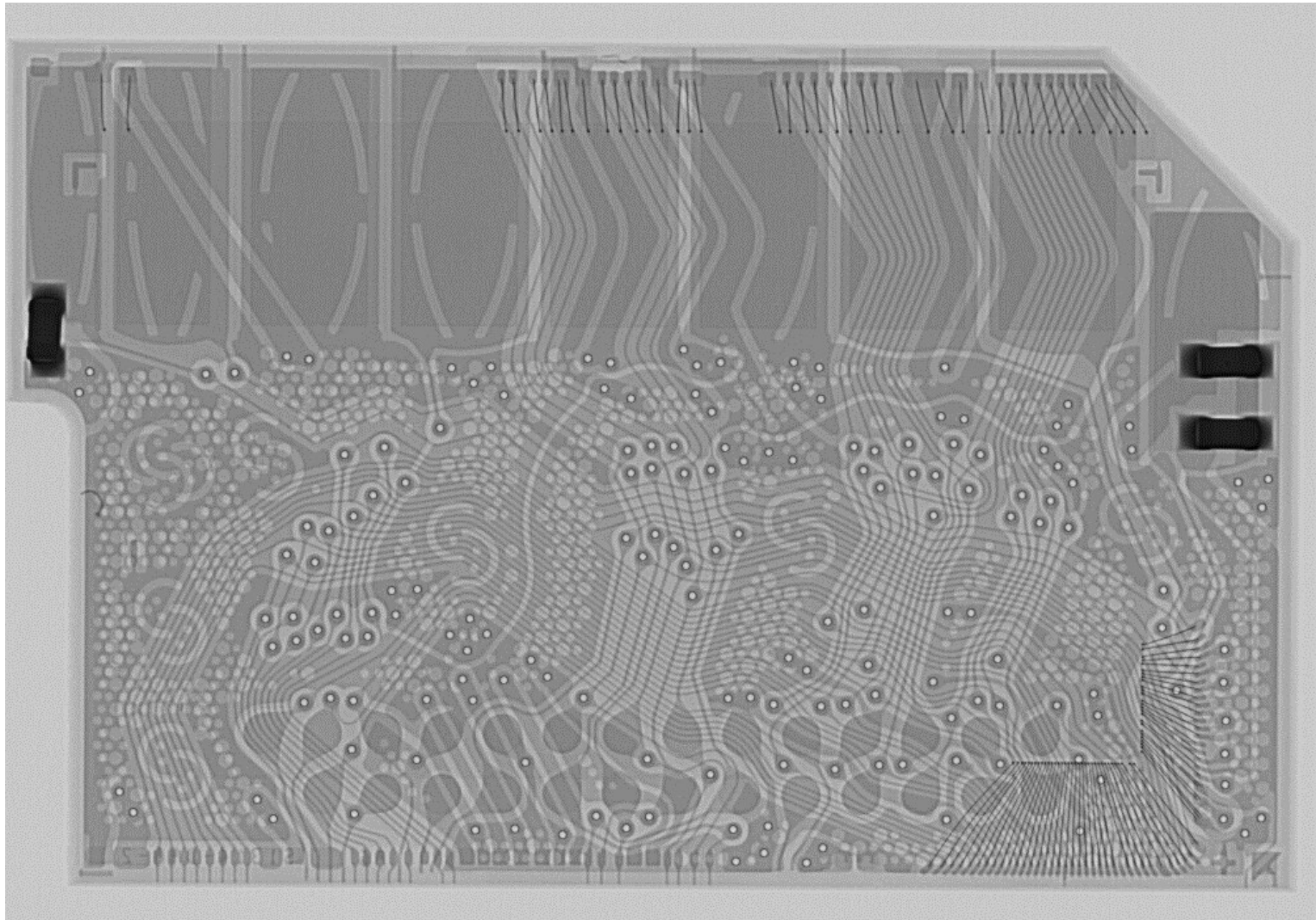


Top view shows the wire bond footprint (red arrows)

- Small area in one corner
- Long line along the edge of the package
- Consistent with a stacked chip structure

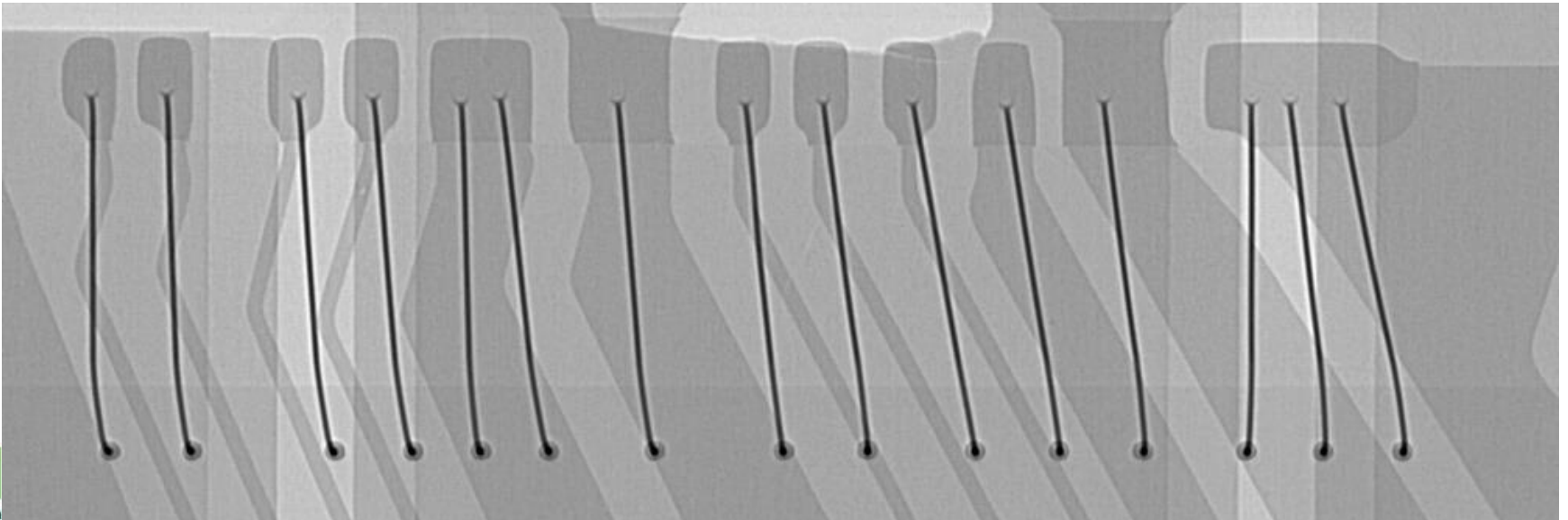
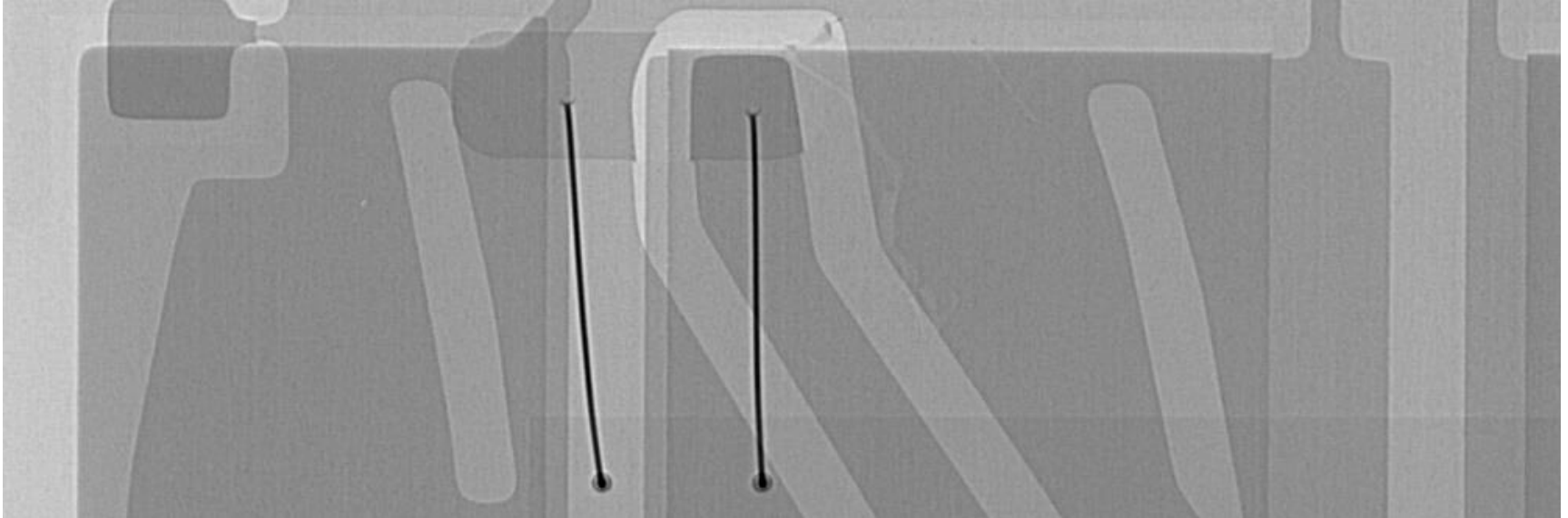


Global View of the Module

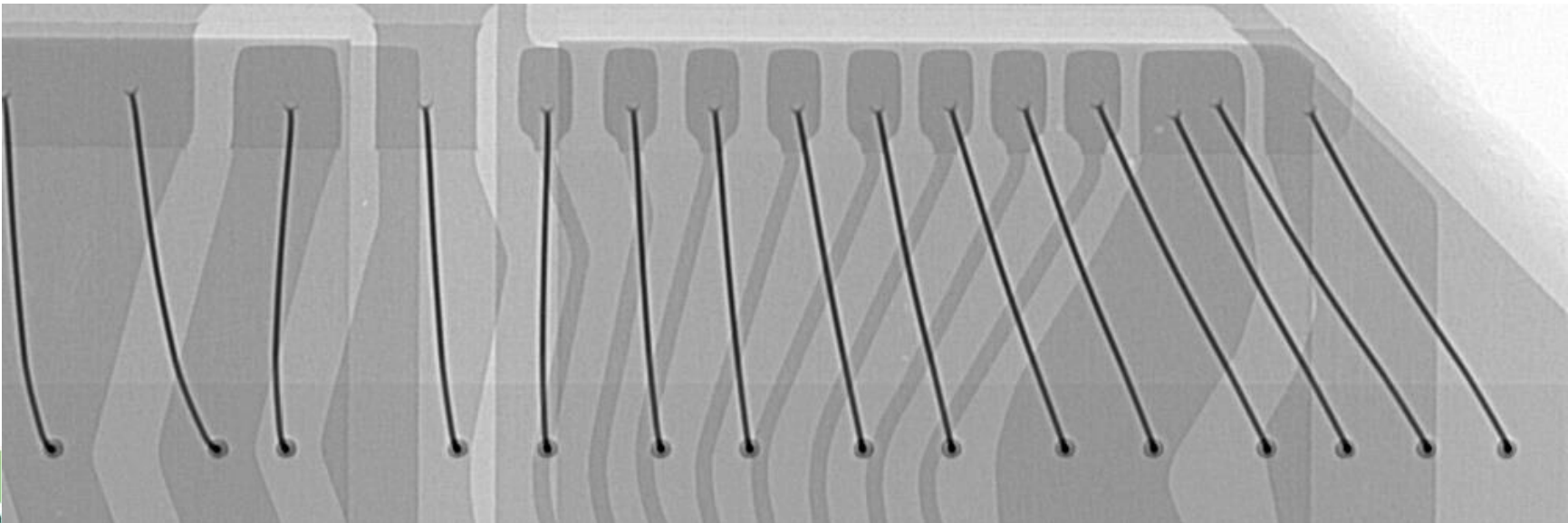
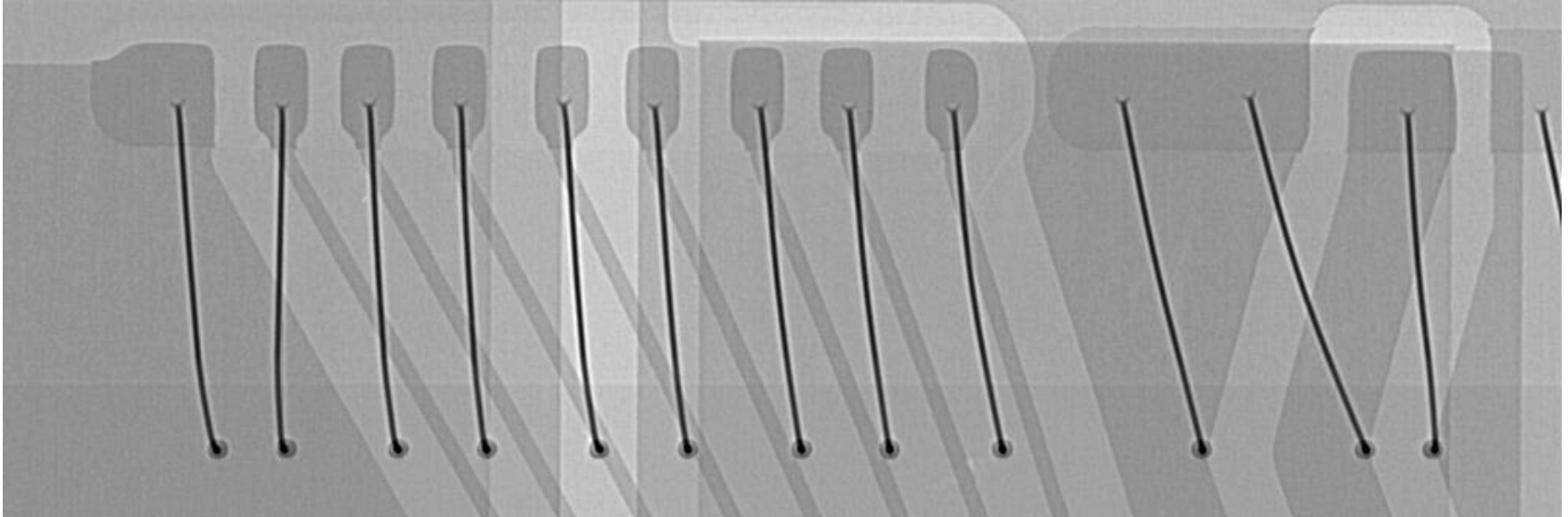


All circuit lines in the interior appear to be intact

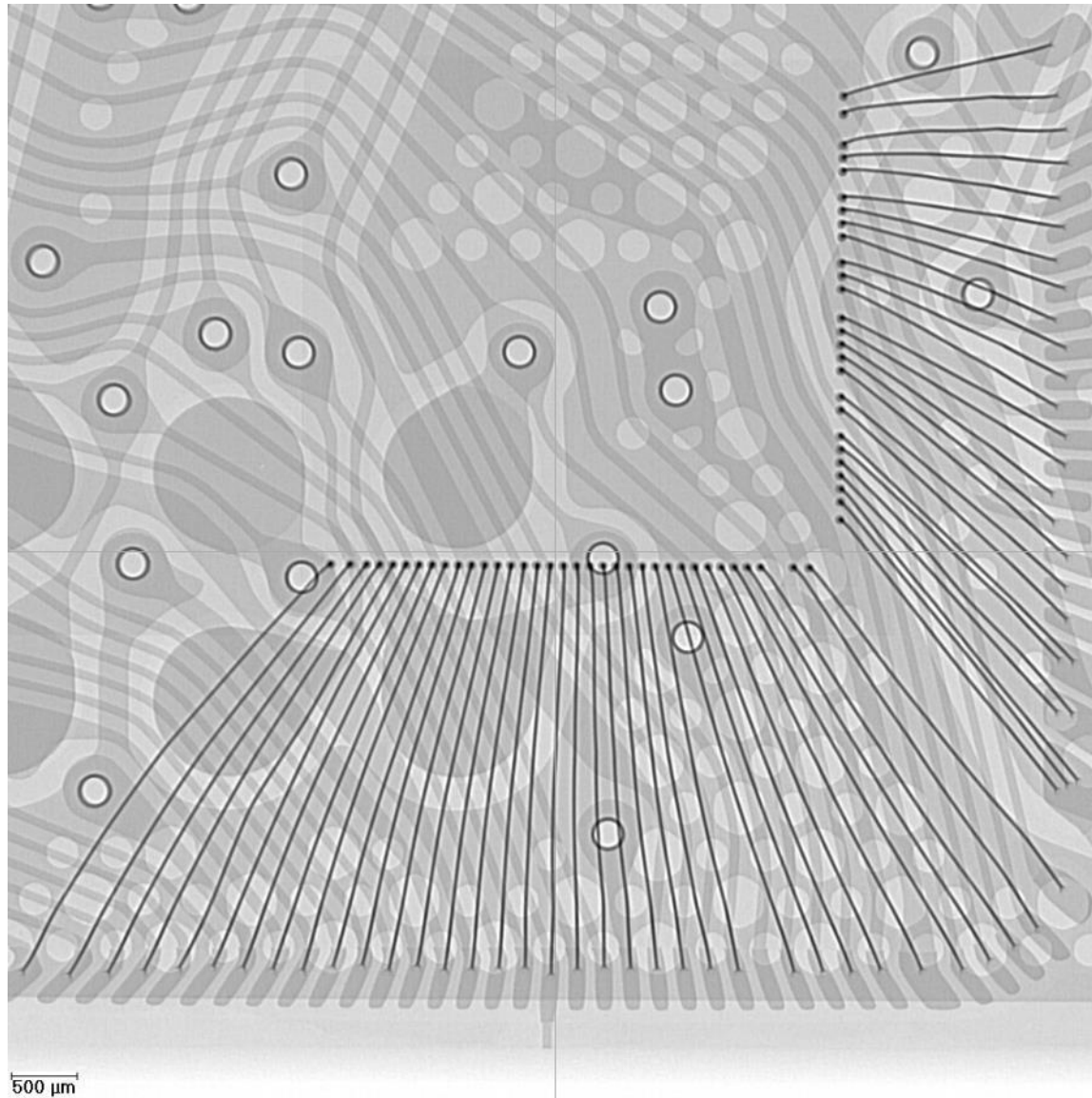
Inspection of the Wire Bonds – No Breaks



Inspection of the Wire Bonds – No Breaks

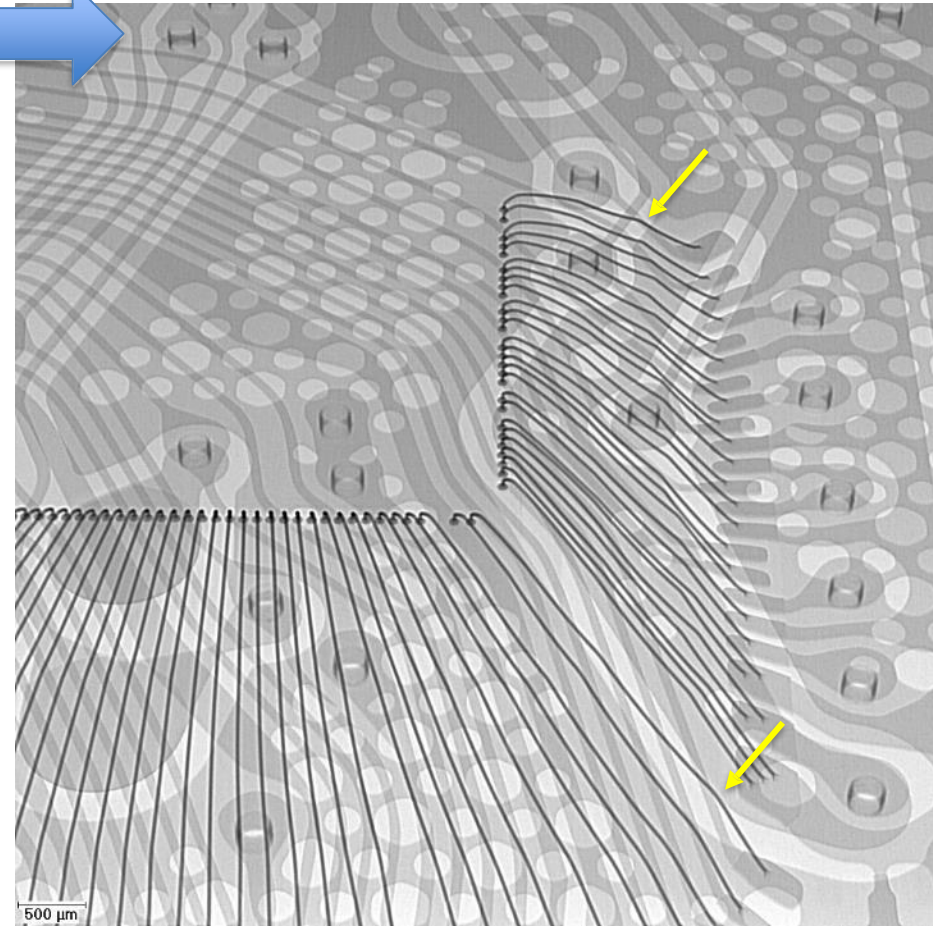
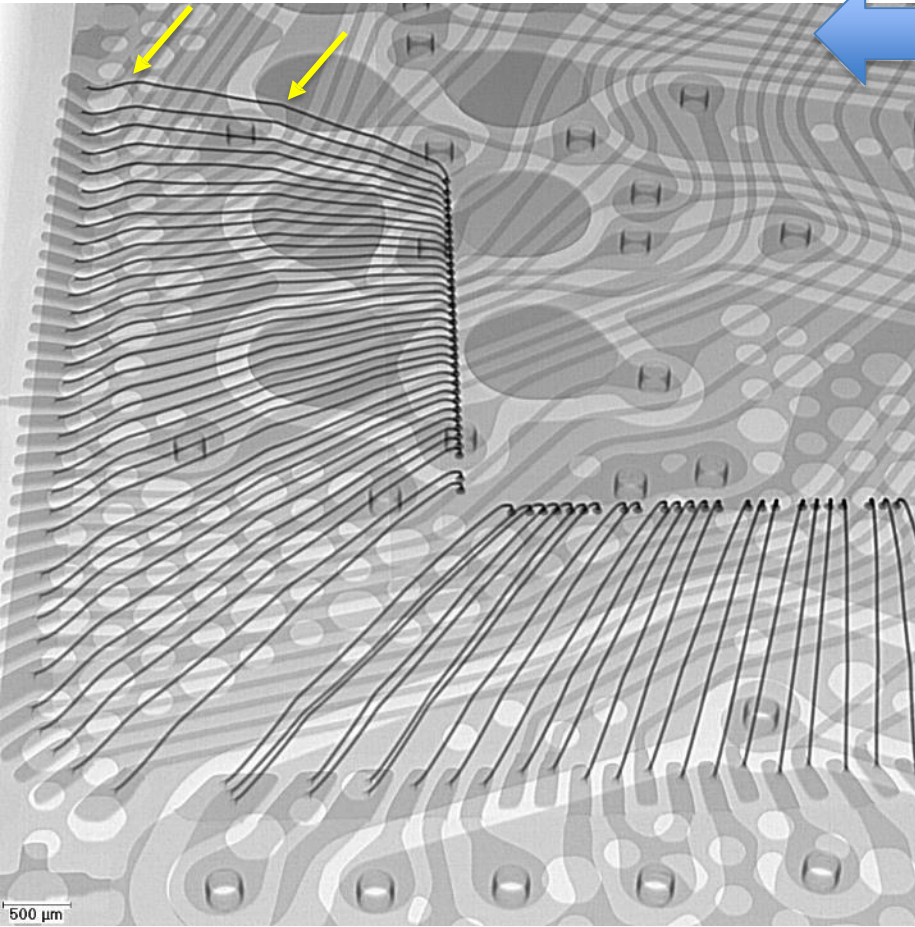


Inspection of the Wire Bonds – No Breaks



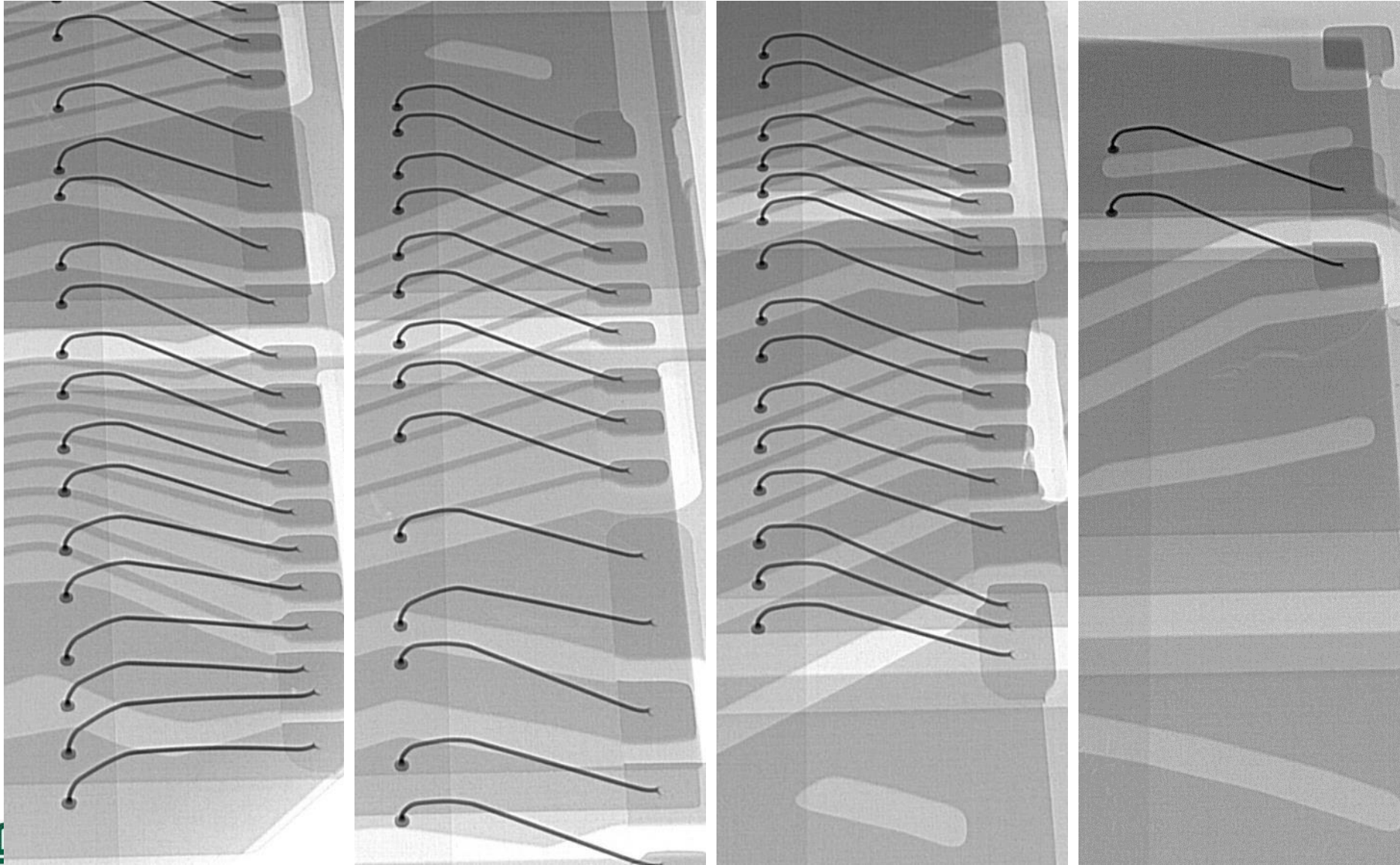
45° Tilt Showing Wire Bonds of the Corner Chip

Rotated 90°



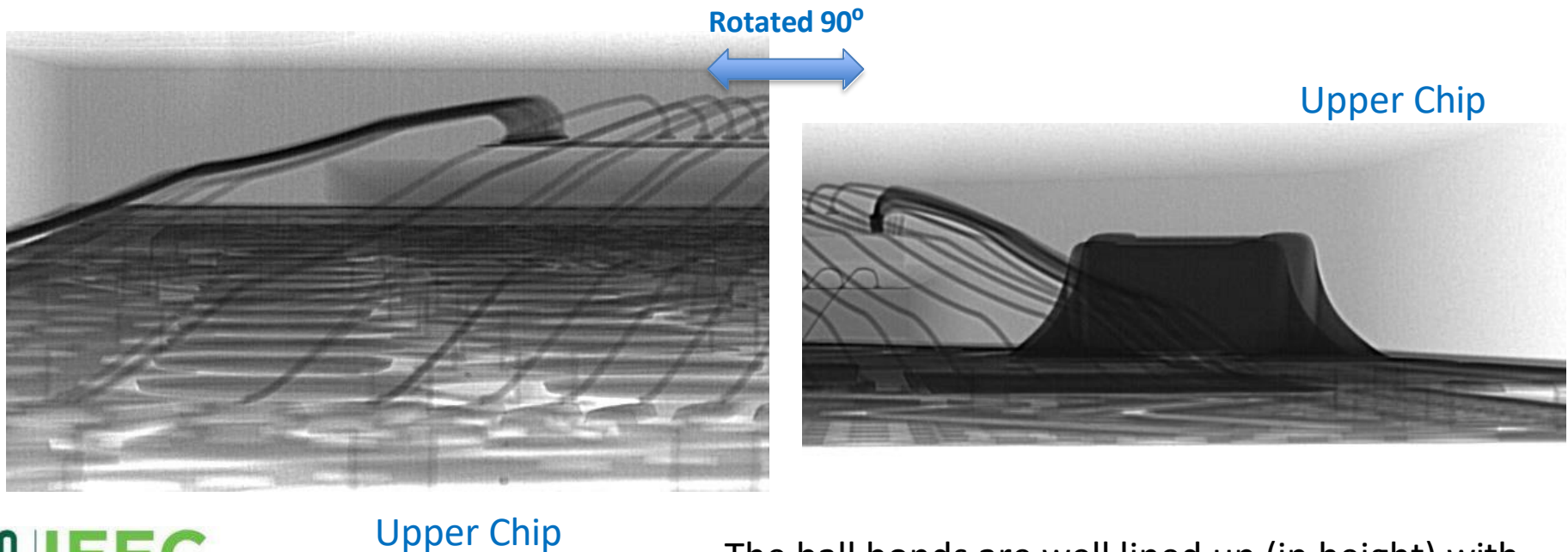
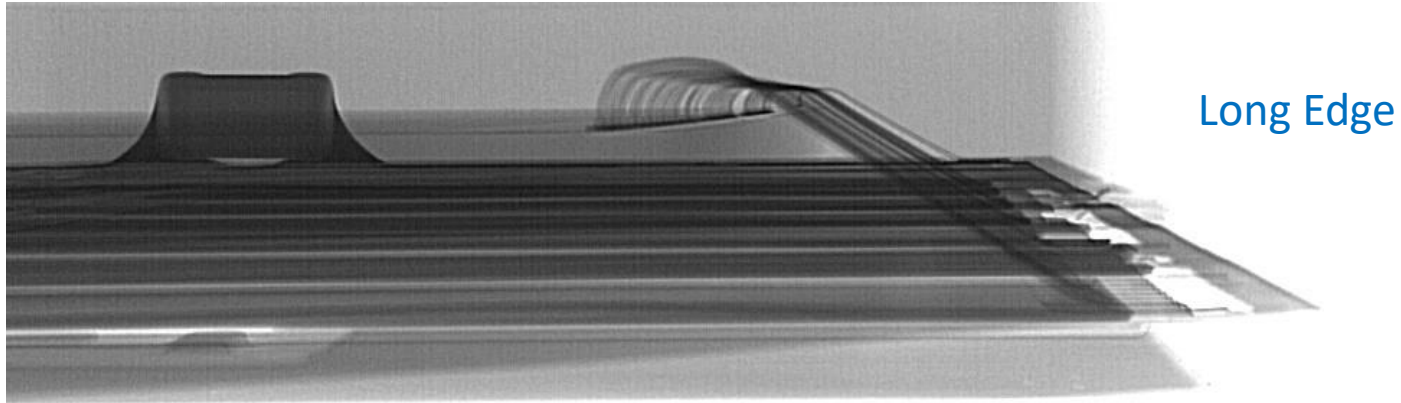
Sharp bend in the wires (yellow arrows) is from the bonding process, not from a mechanical bend or crack of the package

45° Tilted View of the Wire Bonds Along the Package Edge



All wire bonds well formed with no apparent breaks

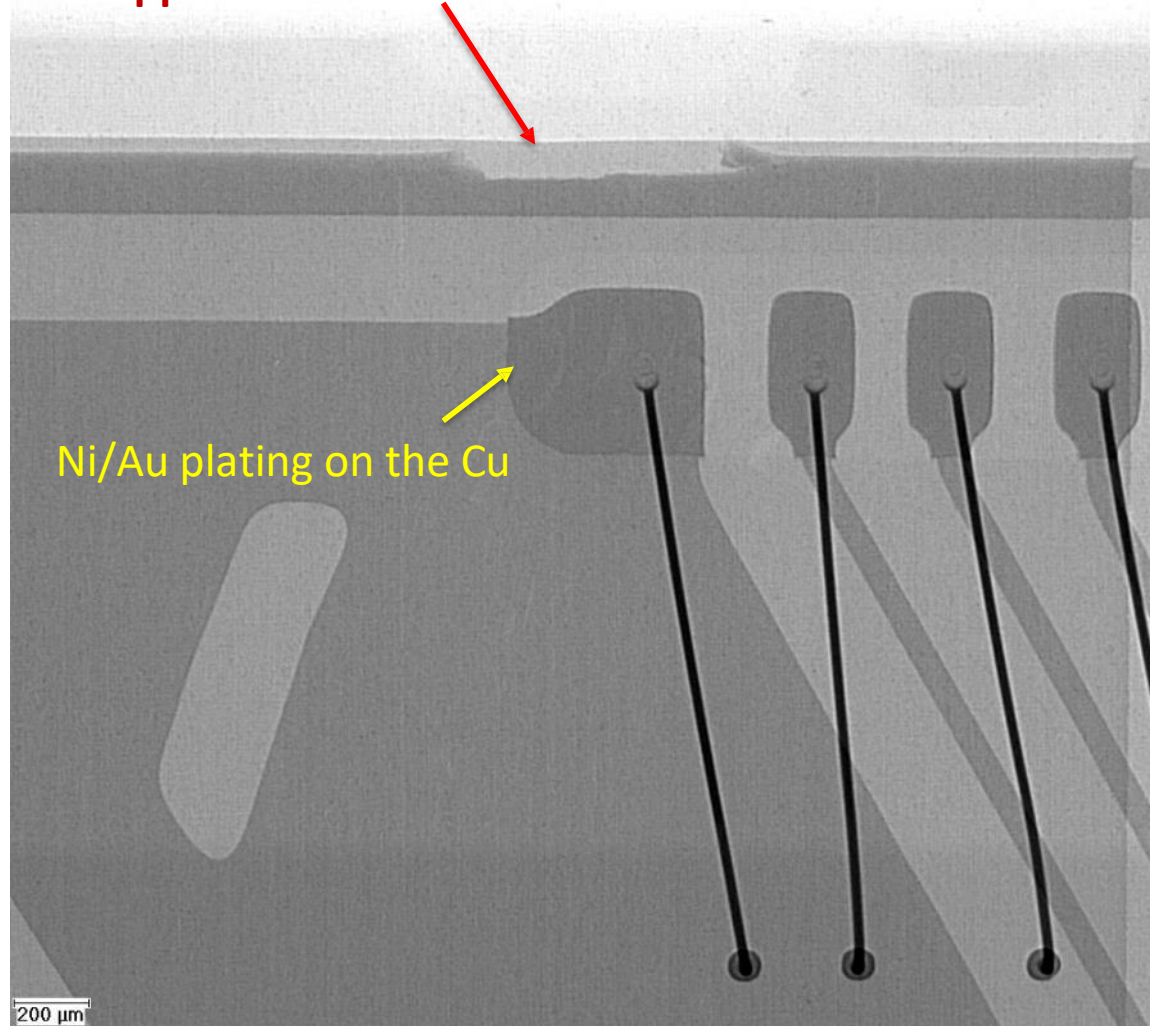
End View of the Rows of Wire Bonds (Note the Ball Bonds)



The ball bonds are well lined up (in height) with no evidence of being lifted from the chip

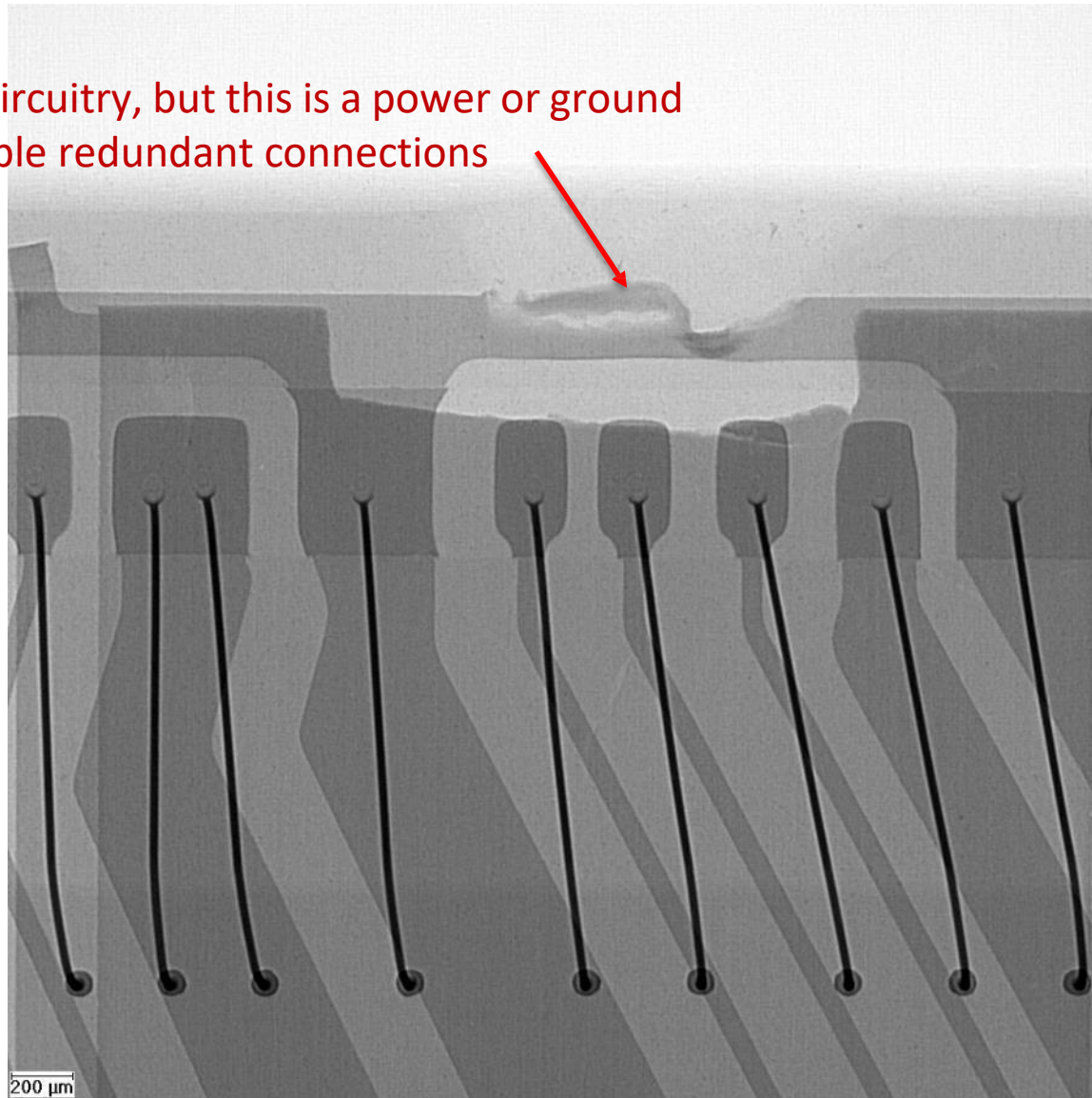
Zoomed View of the Peripheral Damage

Damage does not appear to have severed the circuit line

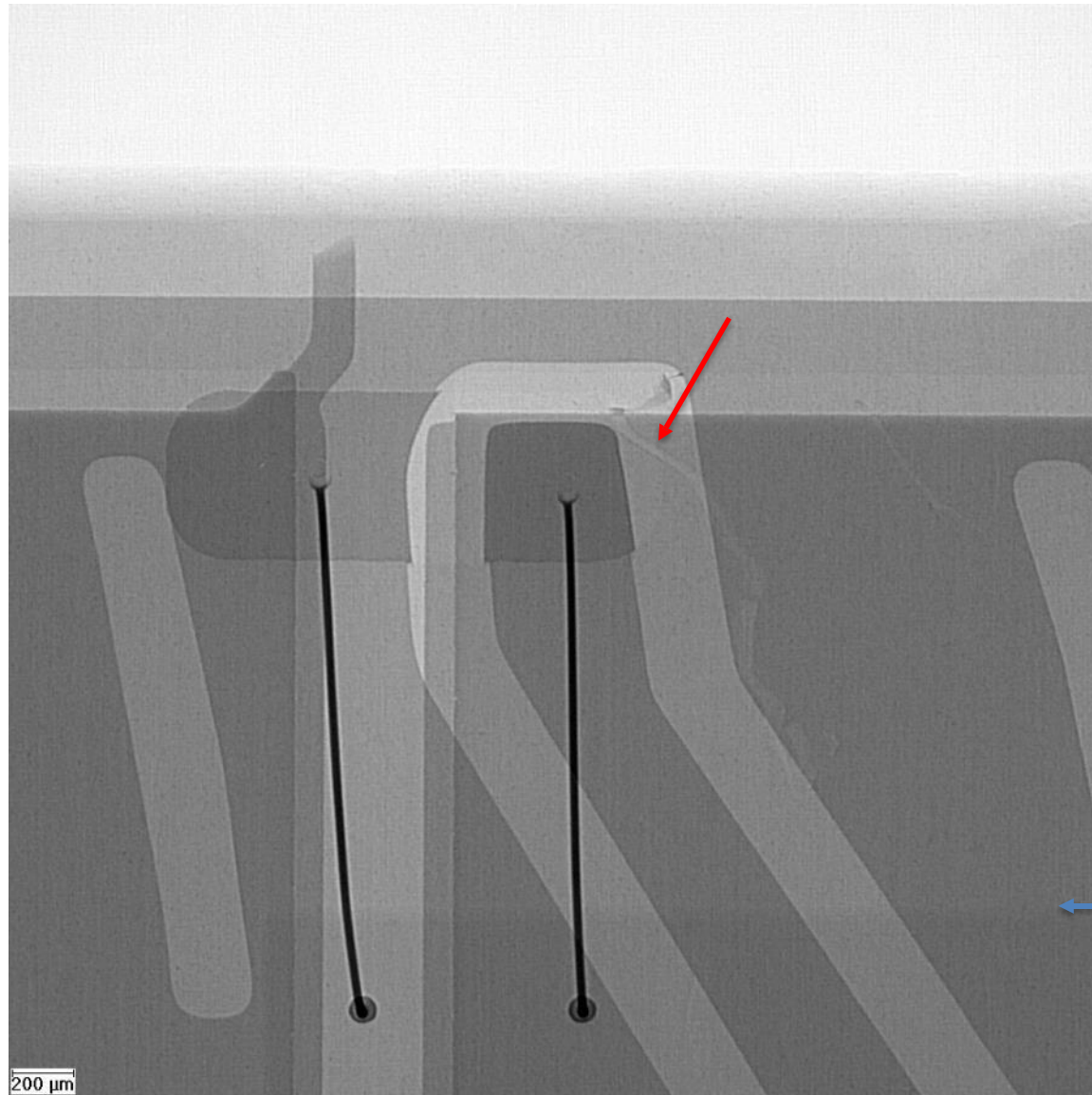


Zoomed View of the Peripheral Damage, cont'd.

Damage to the circuitry, but this is a power or ground which has multiple redundant connections



Crack in the Package, but This Stops Before Reaching the Chip

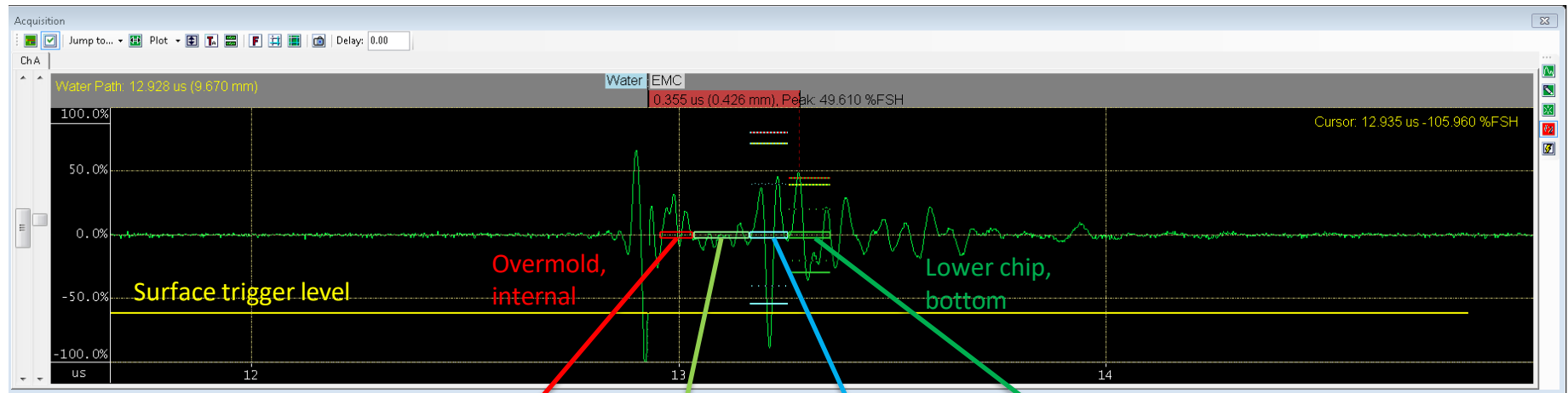


Shadow of
the chip

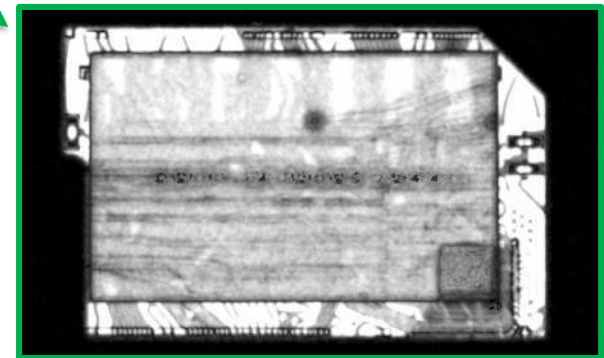
Section 3

ACOUSTIC MICROSCOPY

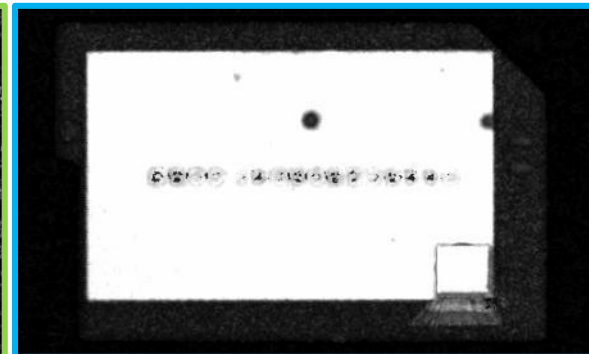
Gate Setup – 50 MHz Transducer



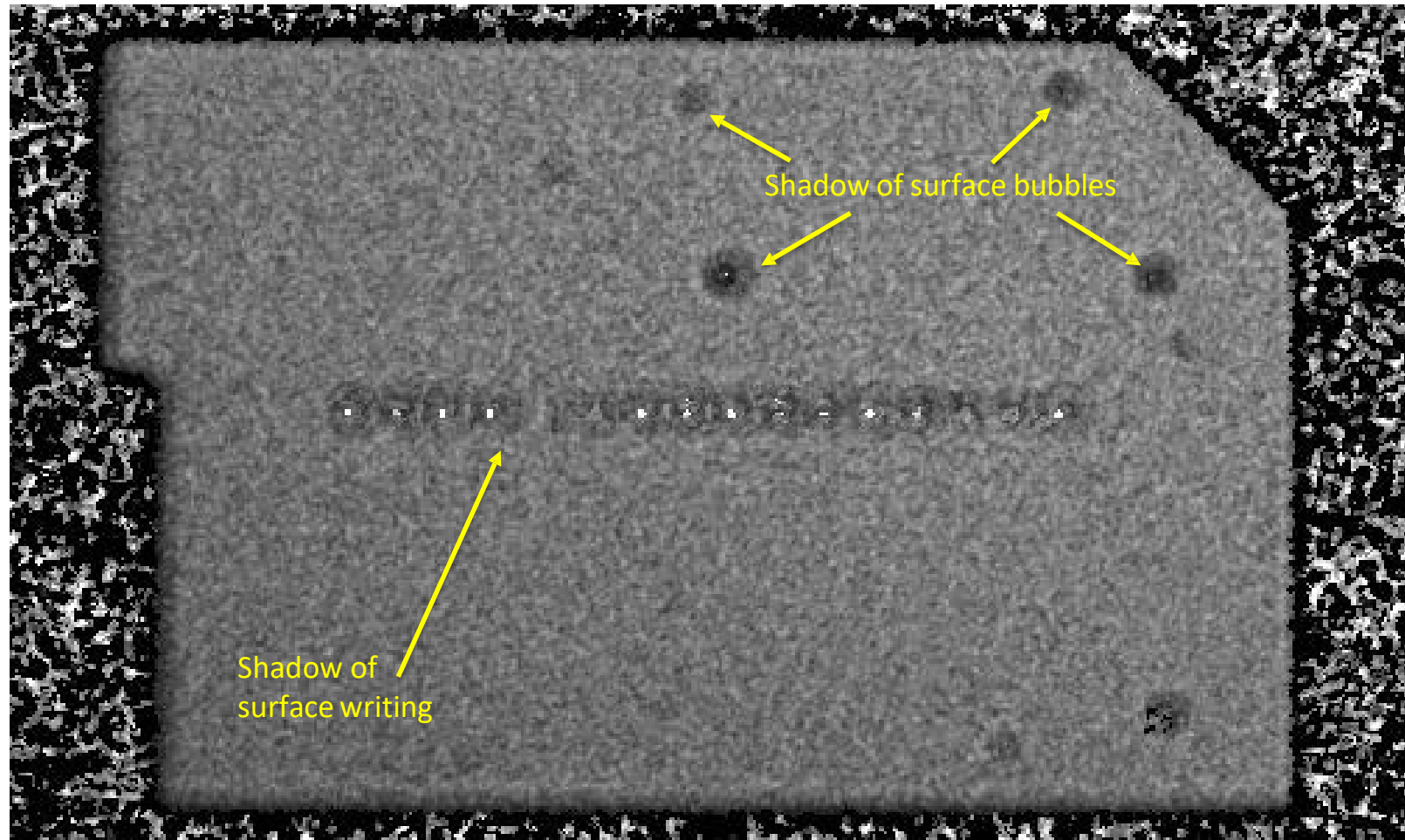
Upper chip, top



Lower chip, top

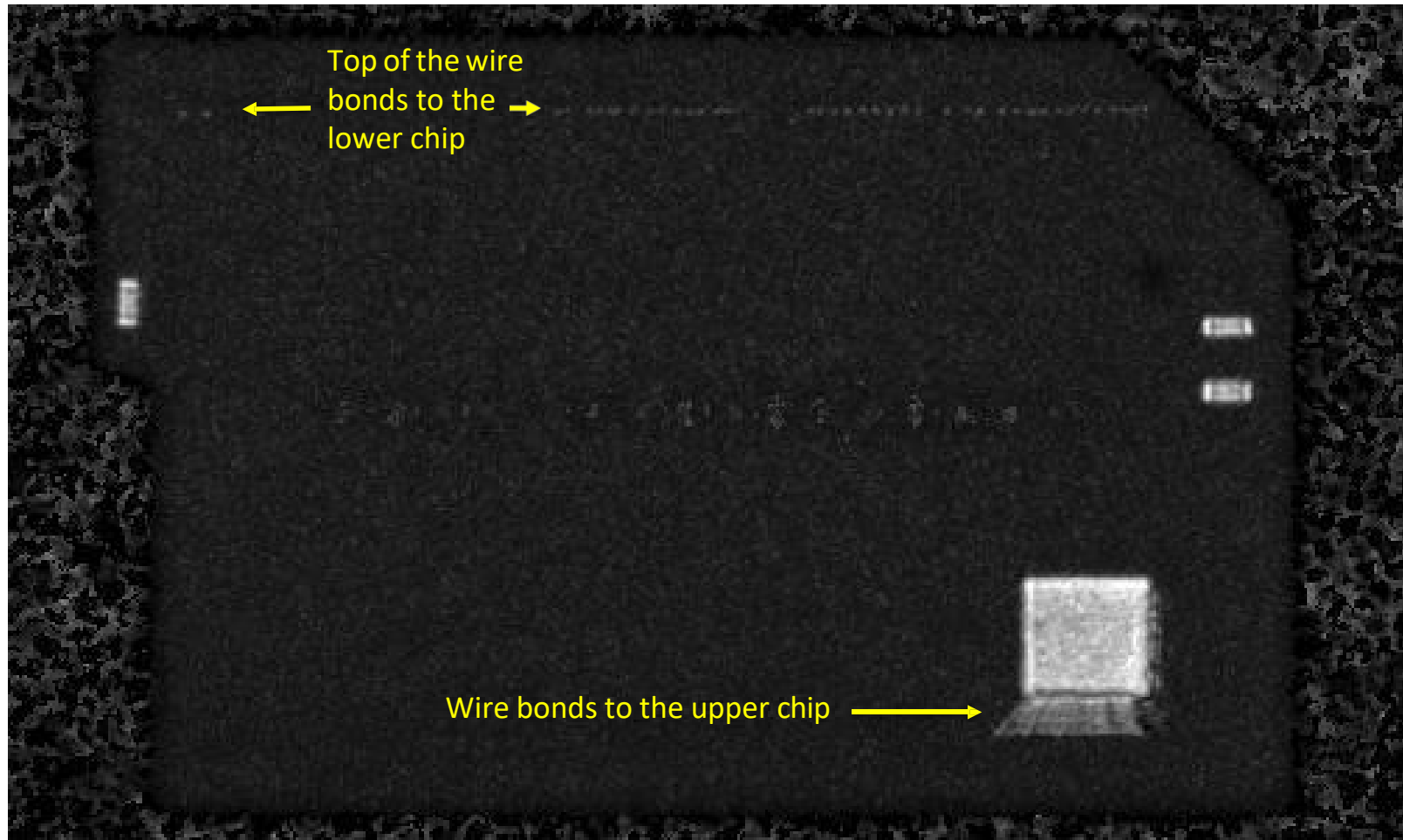


Overmold



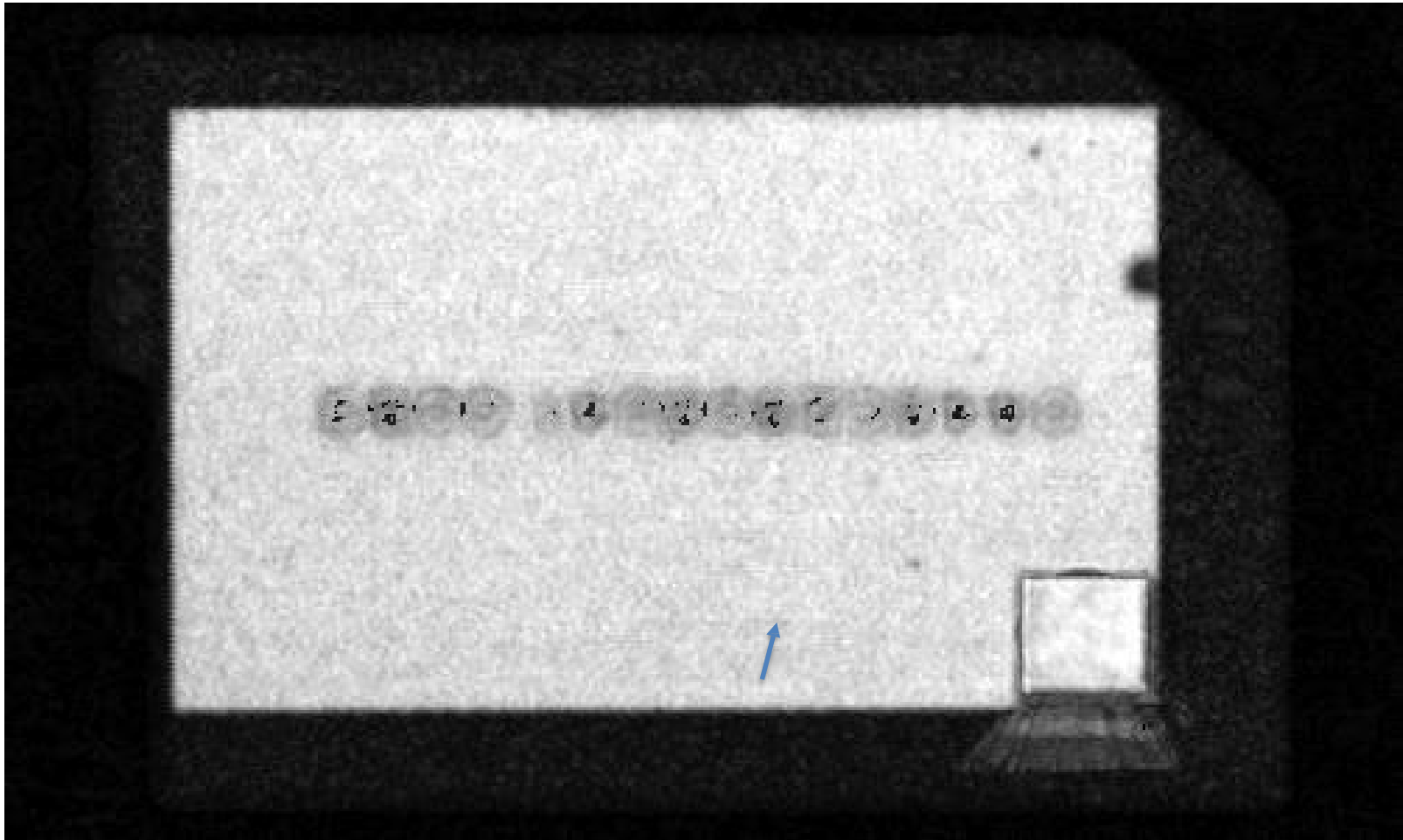
No evidence of damage inside the overmold

Top of the Upper Chip



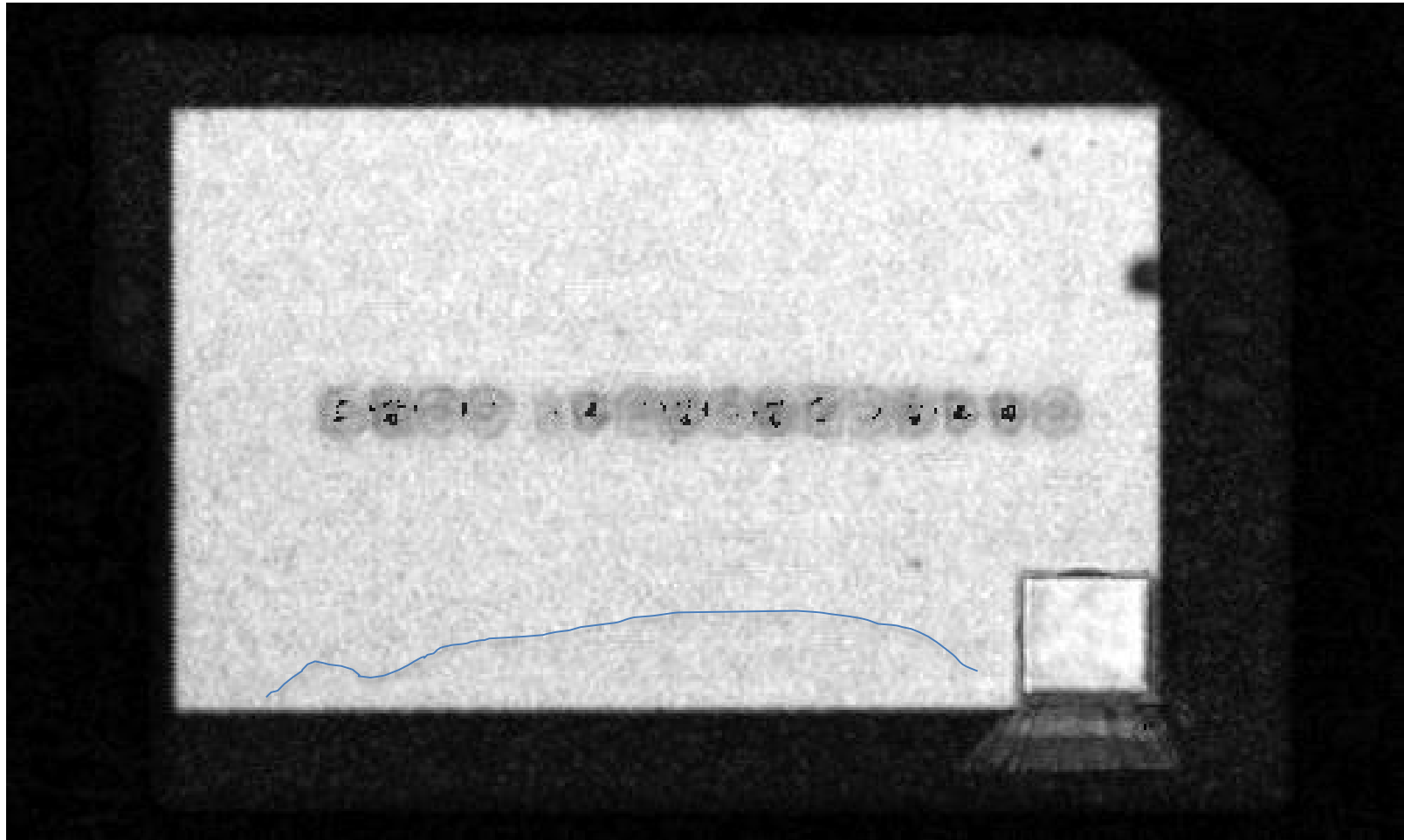
No evidence of damage to the upper chip

Top of the Lower Chip



- Very faint line, possibly indicating a crack (arrow, and c.f. following page for highlight of the line)
- Unclear if this really is a crack, or simply an anomaly related to the molding compound

Top of the Lower Chip with Line Highlighting the Anomaly



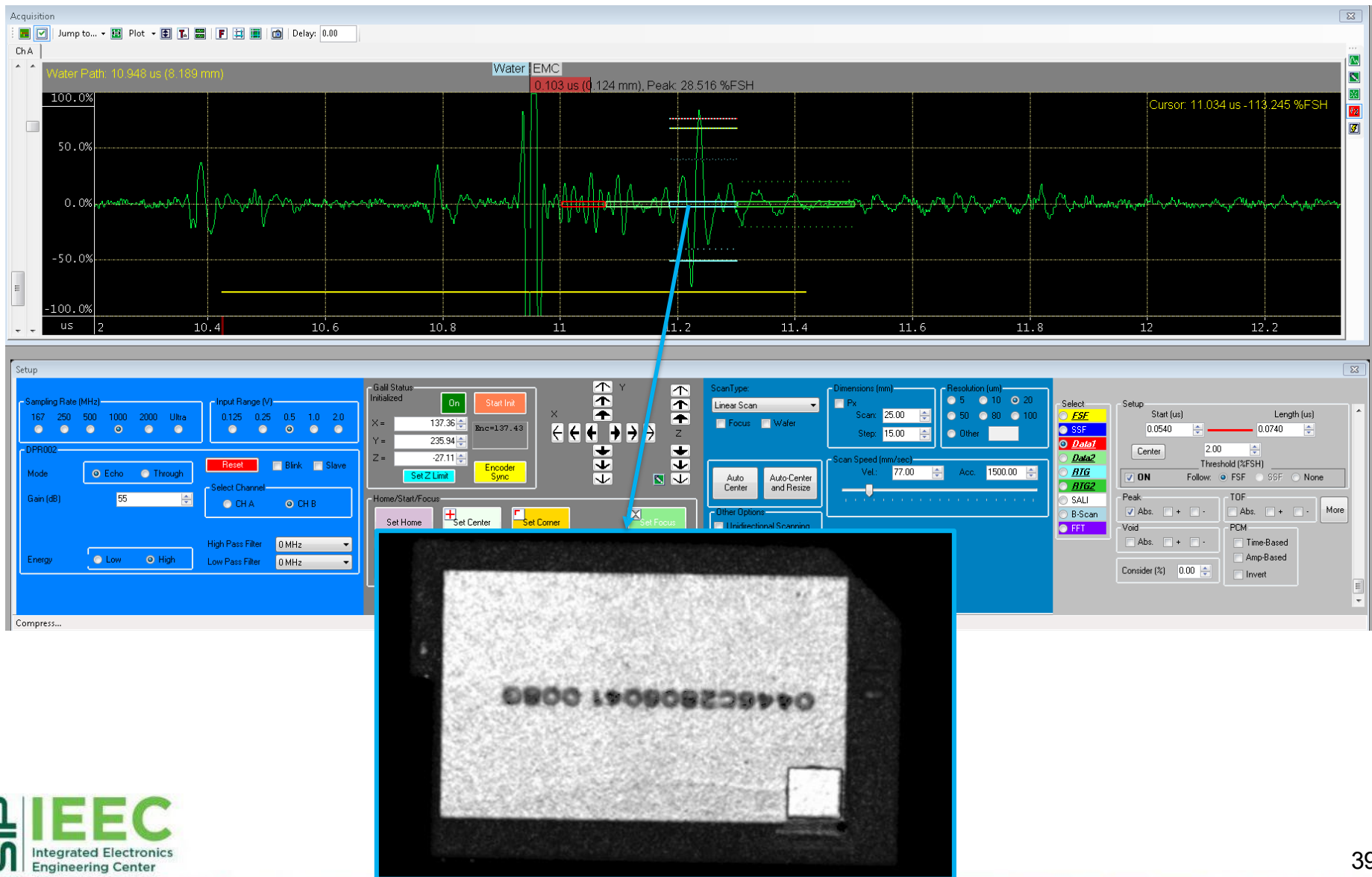
- Very faint line, possibly indicating a crack (c.f. line)
- Unclear if this really is a crack, or simply an anomaly related to the molding compound

Bottom of the Lower Chip (and Laminate Periphery)

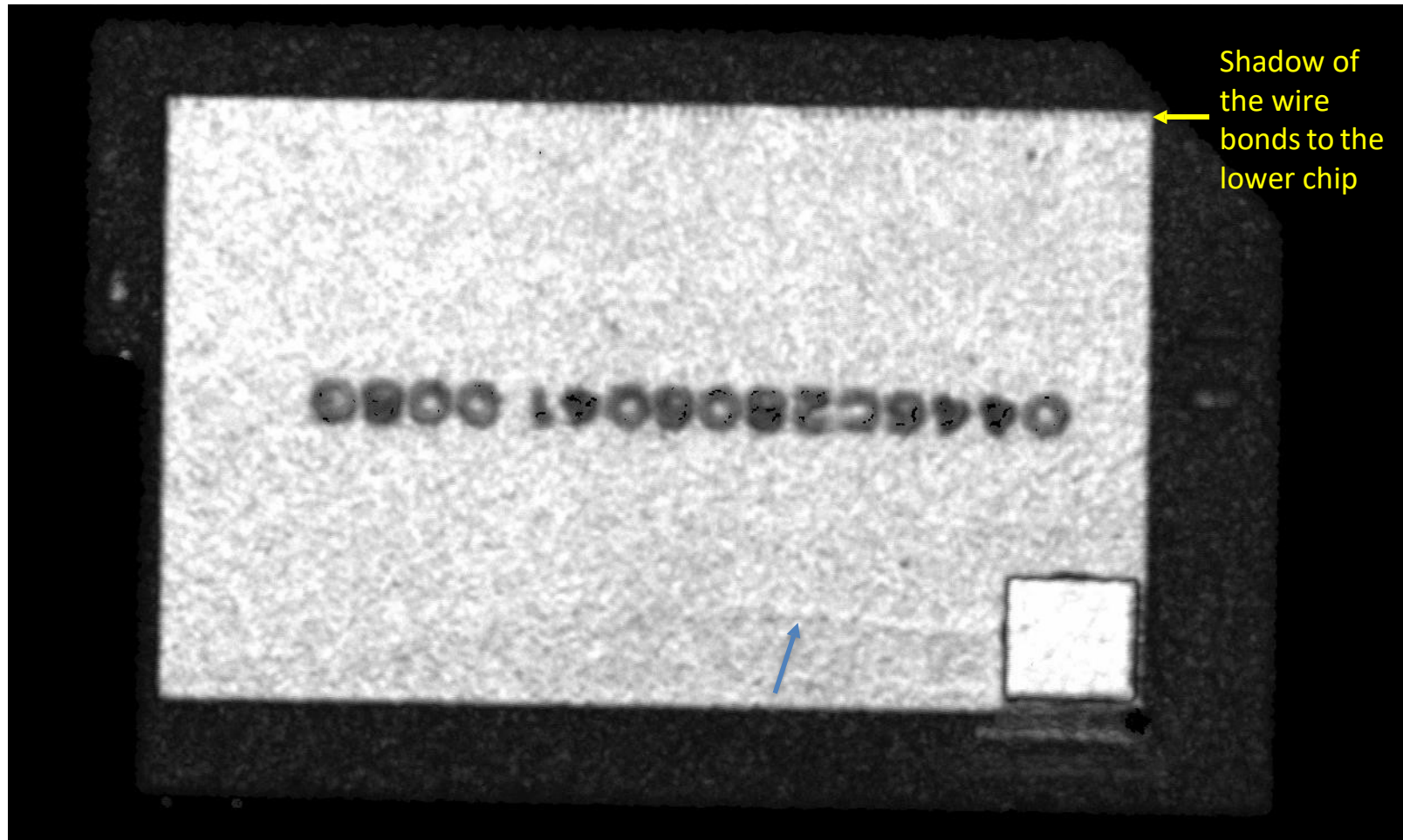


- Horizontal streaks in the area of the lower chip are readily seen
- Unclear if these streaks indicate mechanical damage (hence likely damage to the chip), or if they are simply due to nonuniformities in the chip adhesive

Examination of the Lower Chip with a Higher Frequency Transducer (150 MHz)

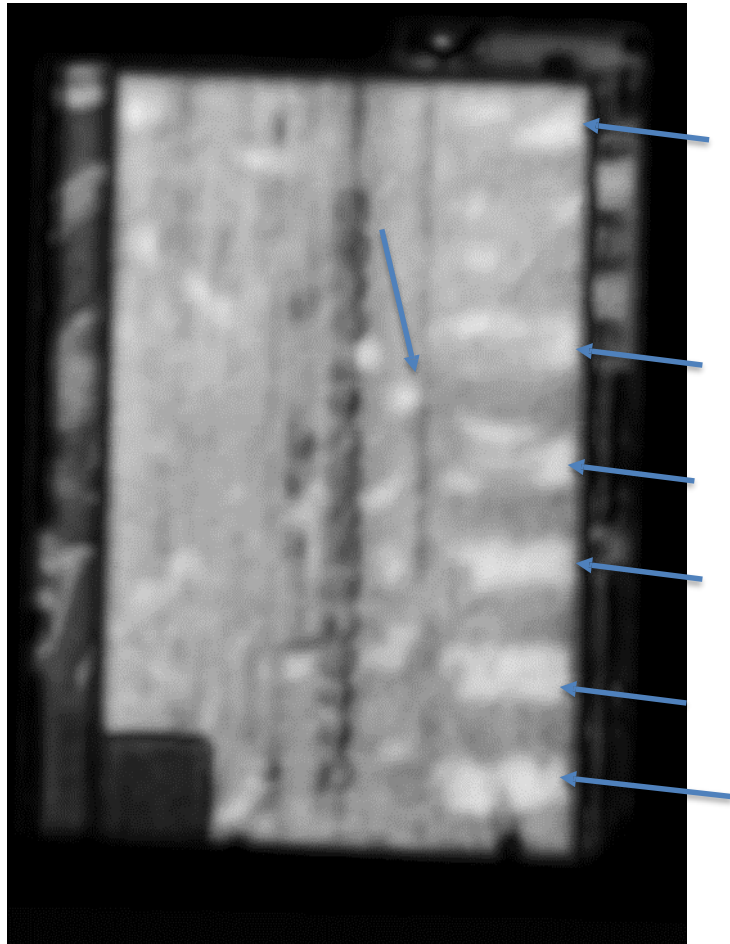


Top of the Lower Chip with a 150 MHz Transducer

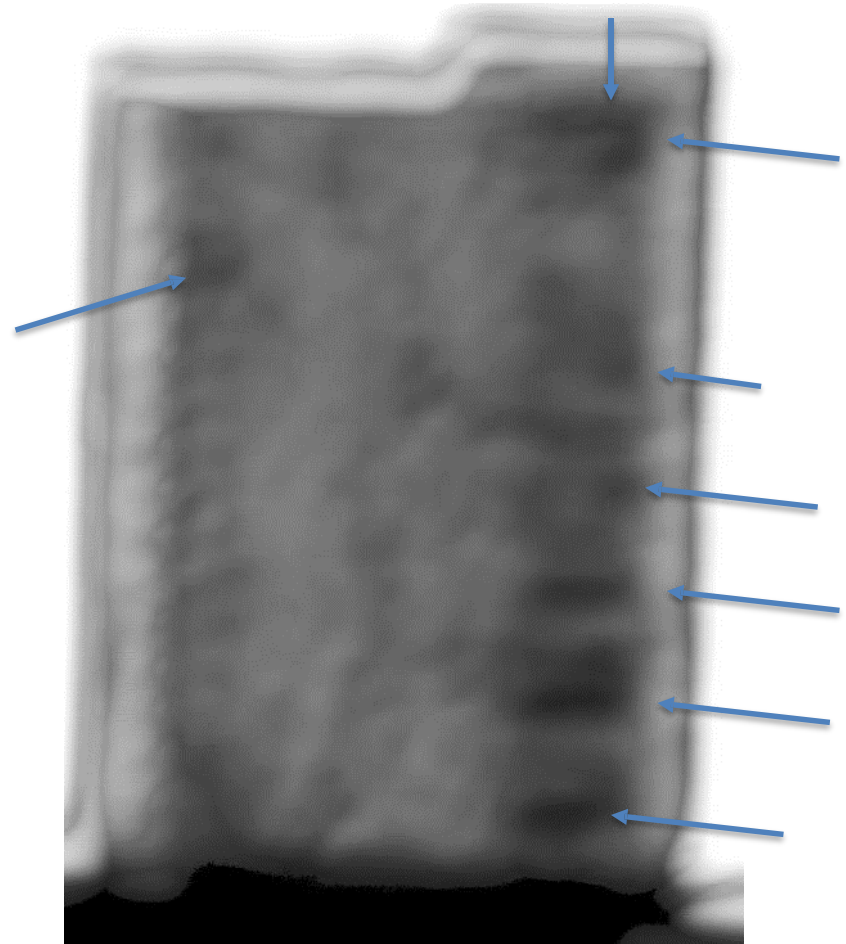


- Very faint line, possibly indicating a crack (blue arrow)
- Even with the higher resolution transducer, it remains unclear if this really is a crack, or simply an anomaly related to the molding compound

Through scan image



Echo image from the bottom of the Lower Chip (and Laminate Periphery)-
Bright areas (blue arrows) represent delaminated areas in the die attach (that reflected most sound).

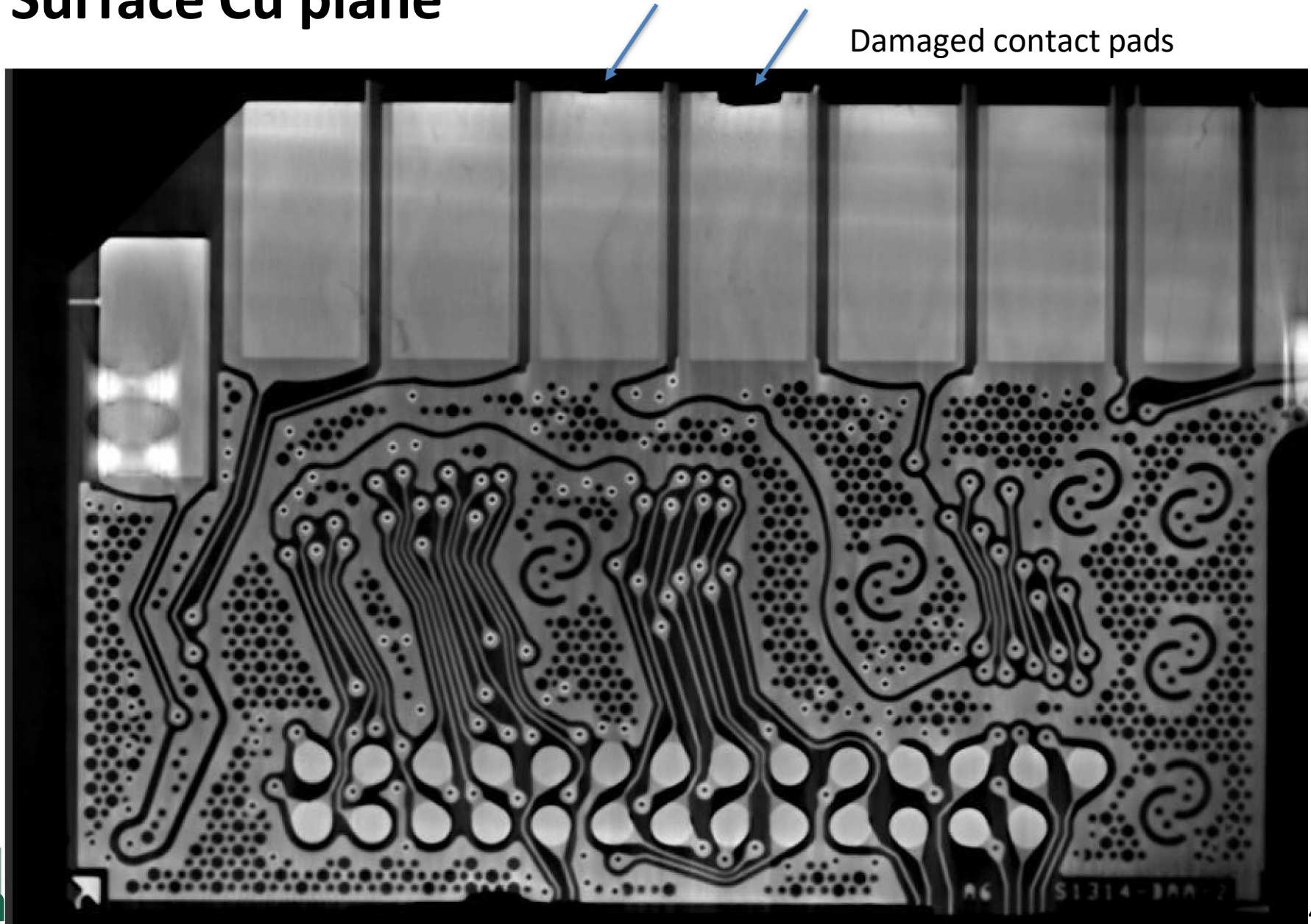


Through scan image: Black areas represent the delaminated areas that blocked sound from transmission (blue arrows)

Section 4

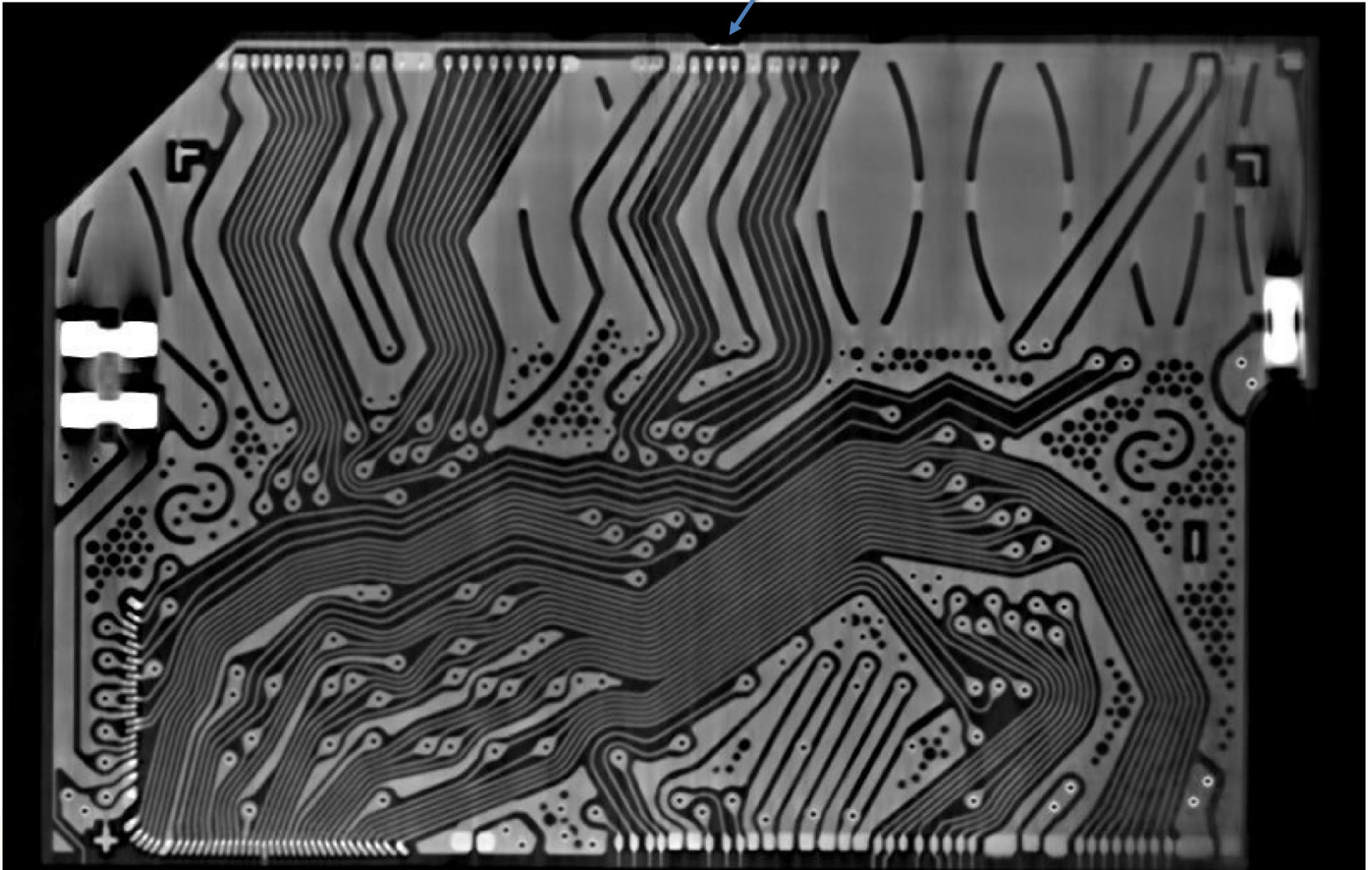
X-RAY CT SCAN

Surface Cu plane

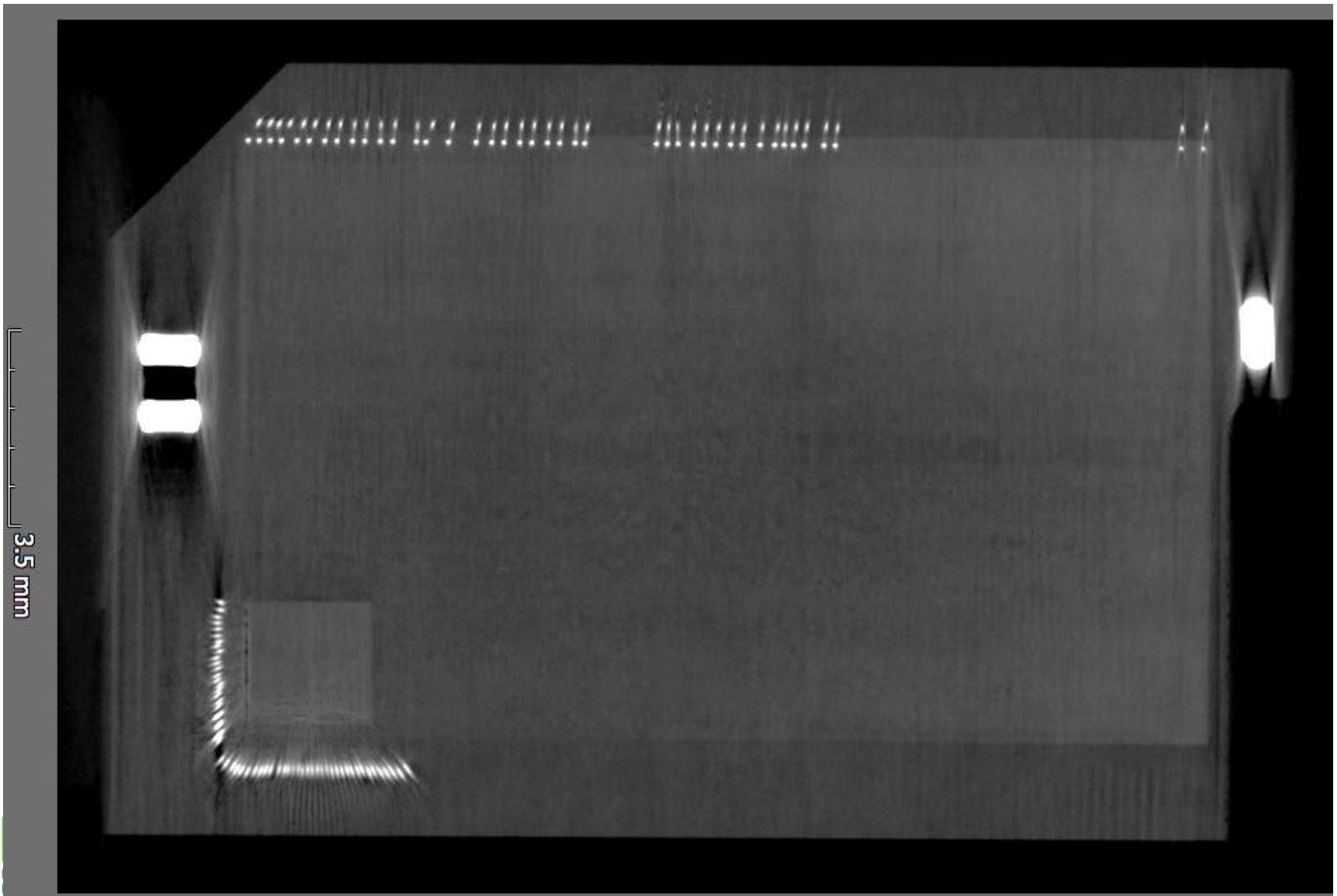


Inner plane

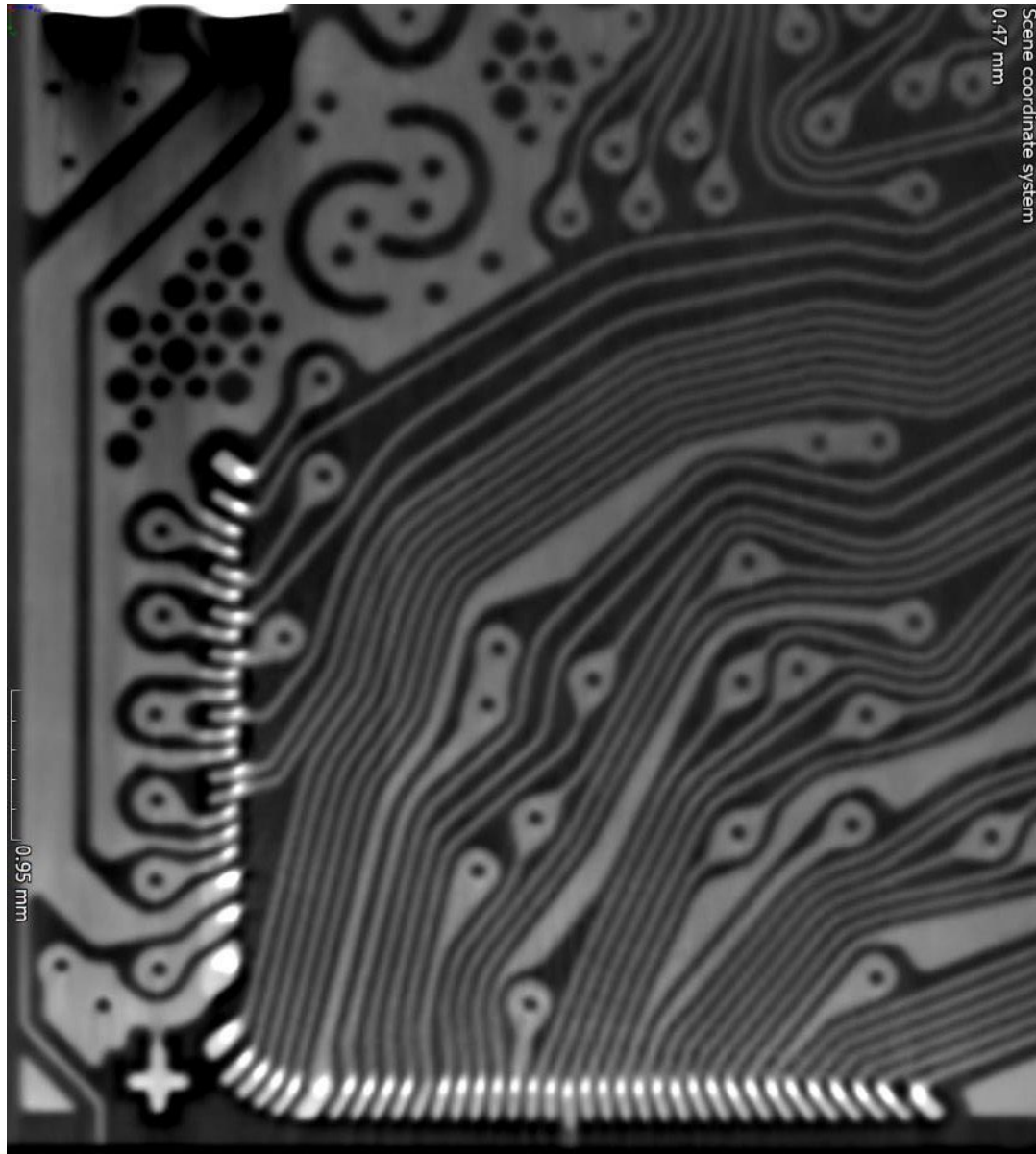
Damaged area



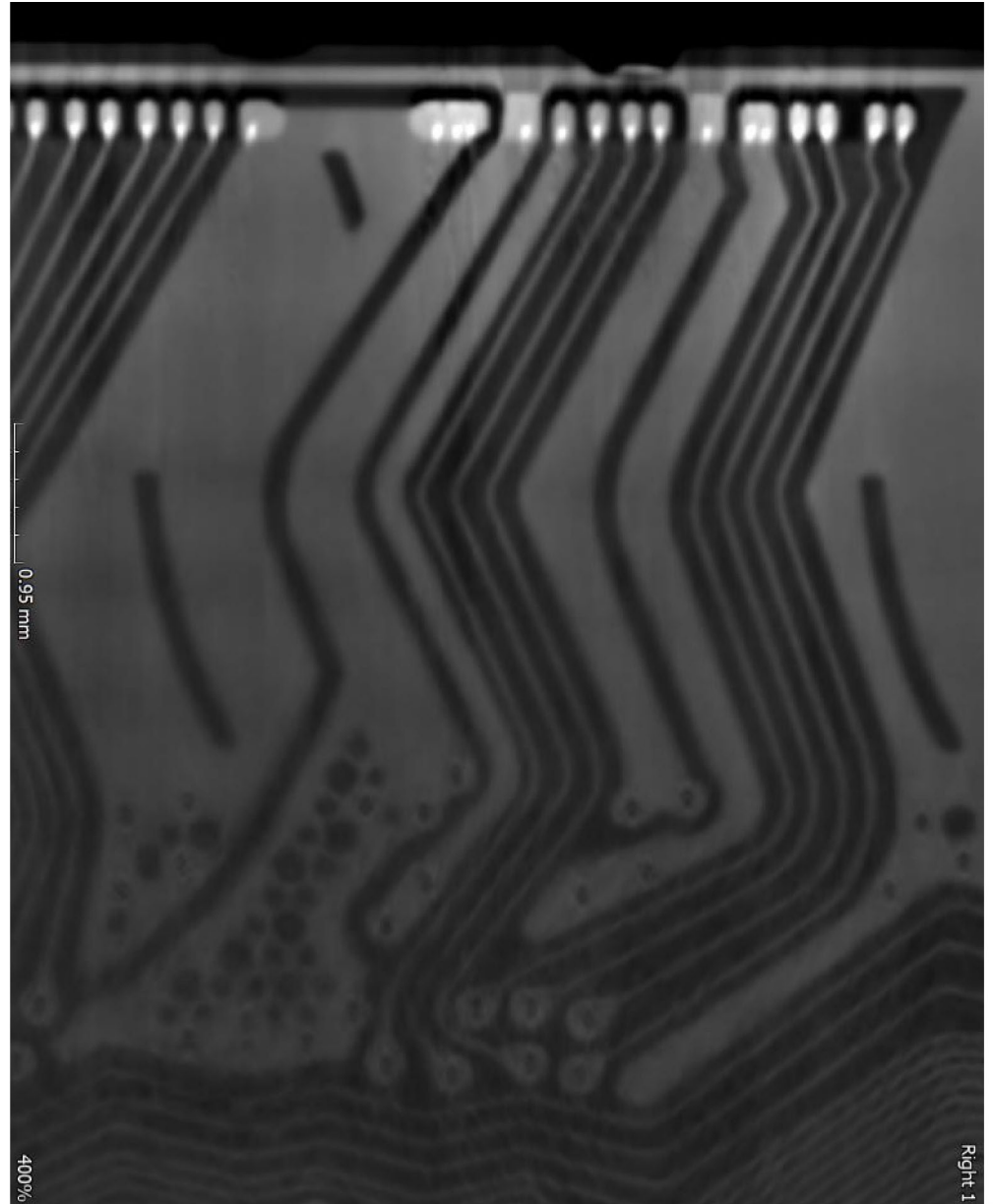
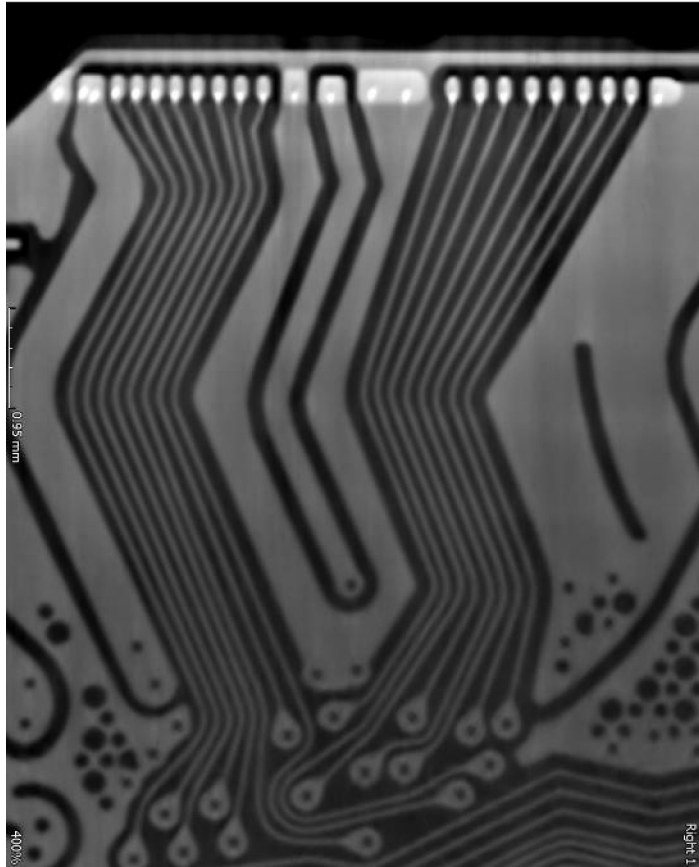
Large and small die- no anomalies detected



Small die wirebonds- no anomalies found



Large die wirebonds



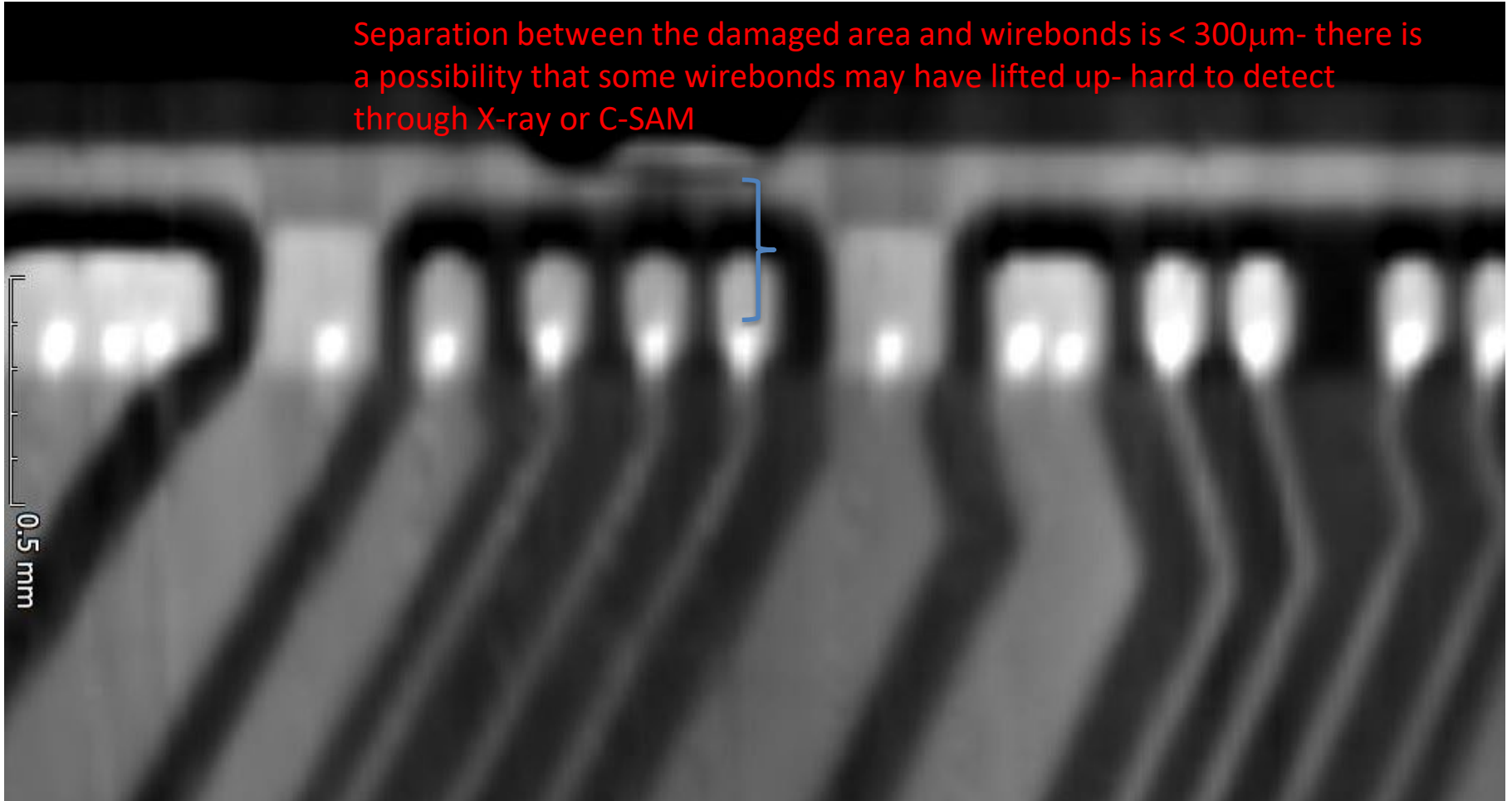
IEEC

UT Integrated Electronics
Engineering Center

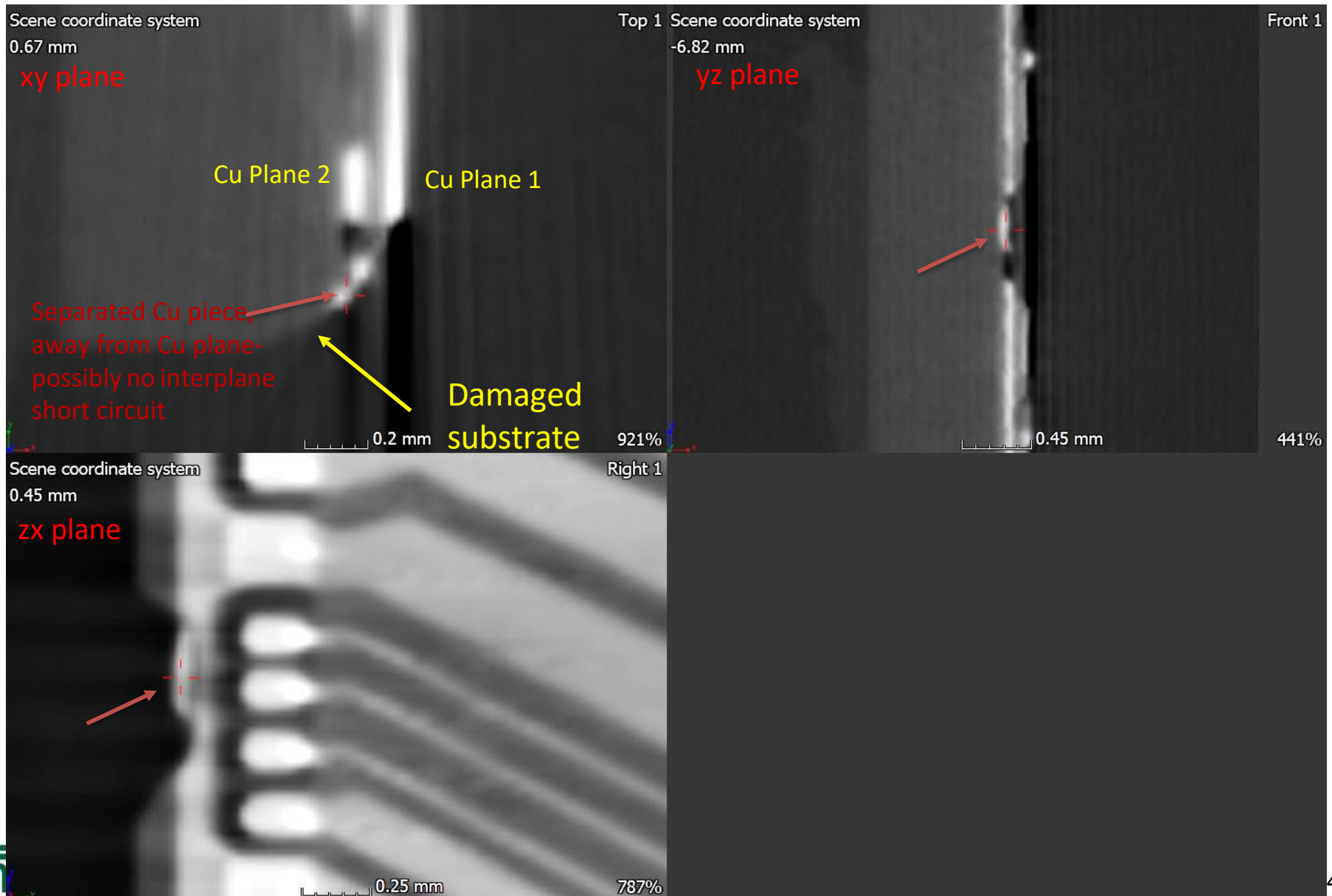
BINGHAMTON UNIVERSITY

Damaged areas:

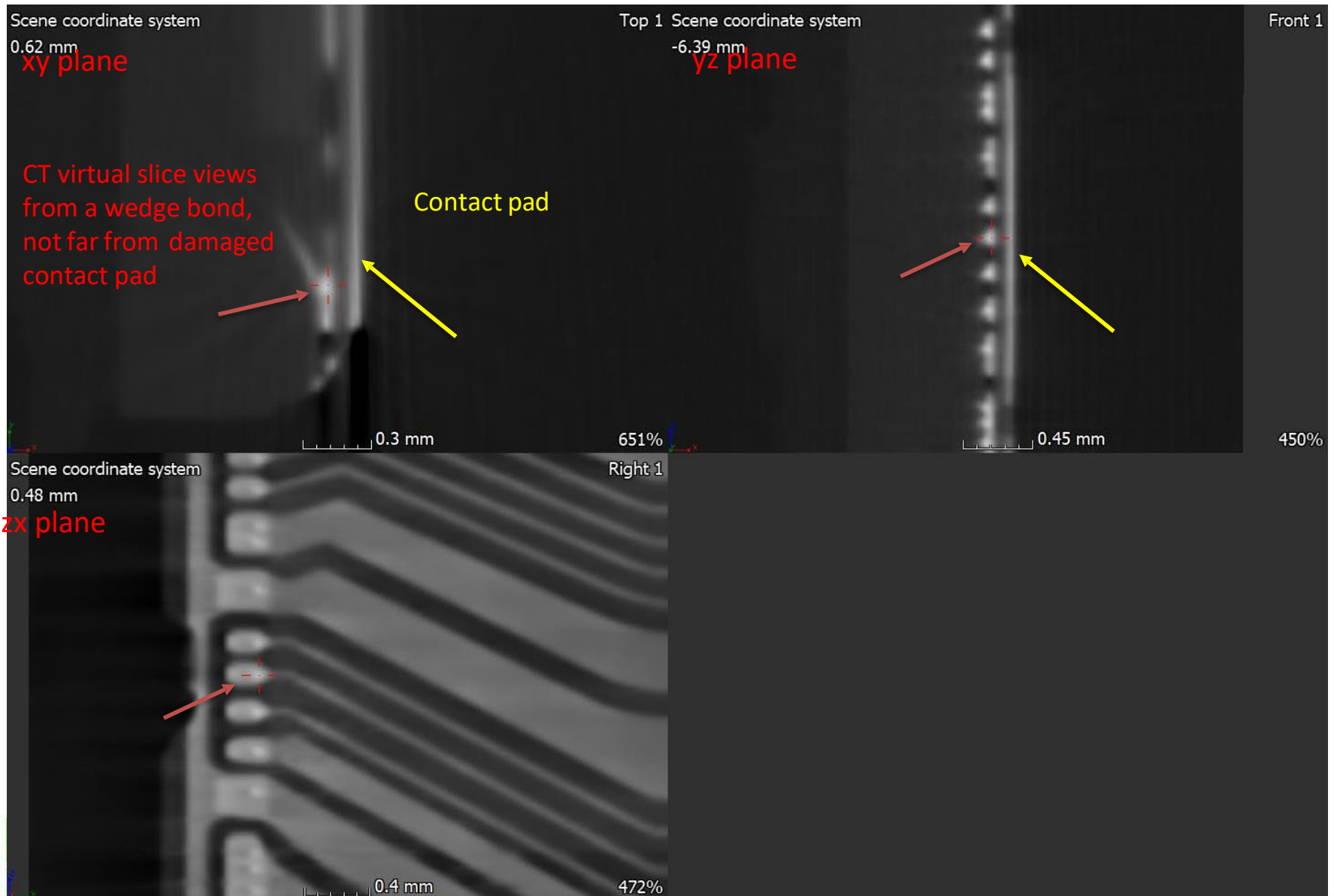
Separation between the damaged area and wirebonds is $< 300\mu\text{m}$ - there is a possibility that some wirebonds may have lifted up- hard to detect through X-ray or C-SAM



CT virtual slice views:

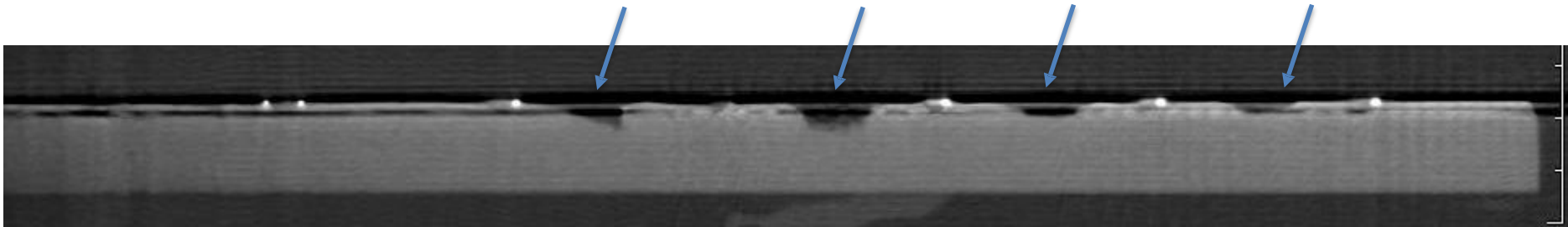


CT virtual slice view of a wedge bond from all axes

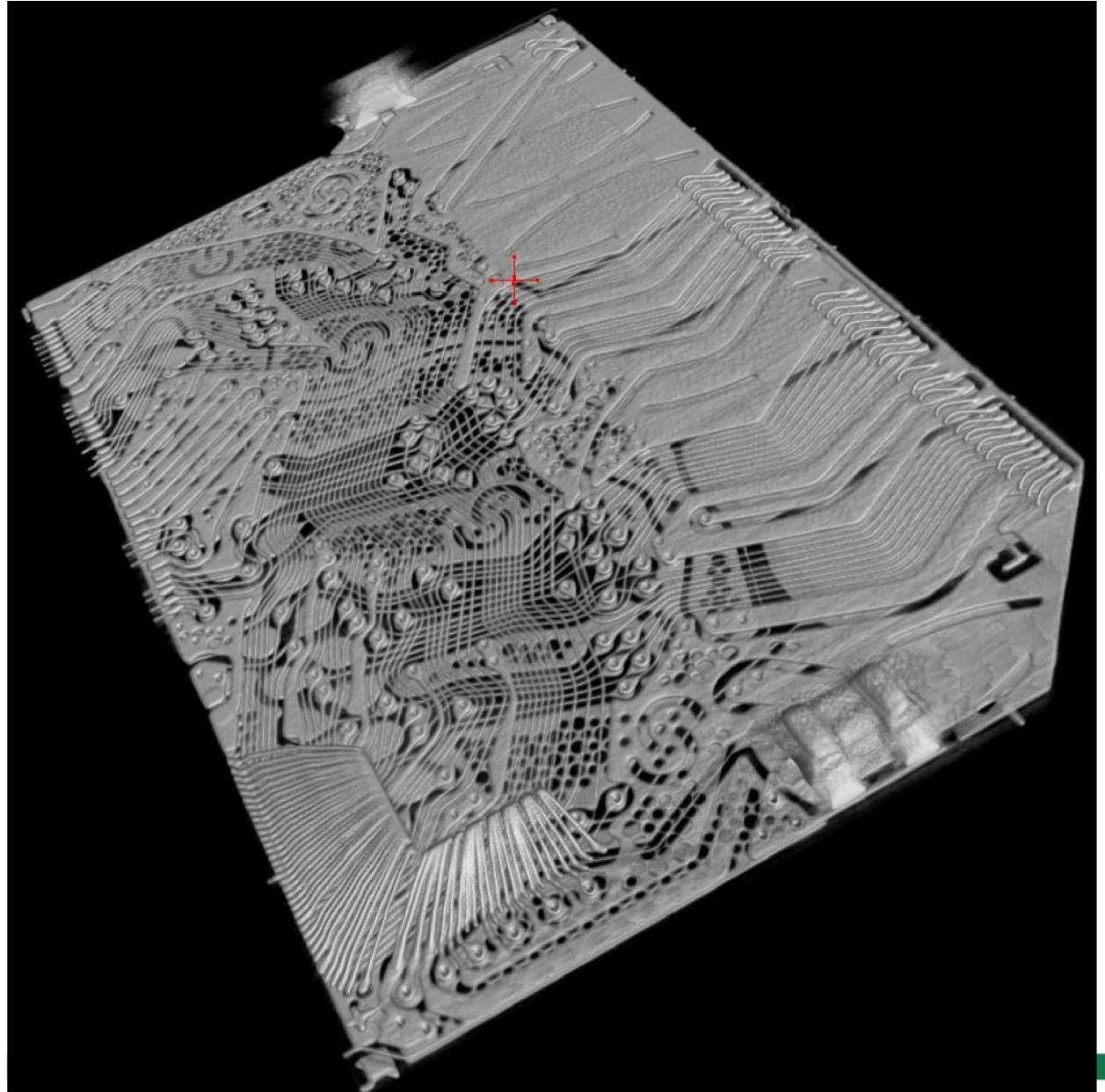


CT slice view showing damage in the chipstrate

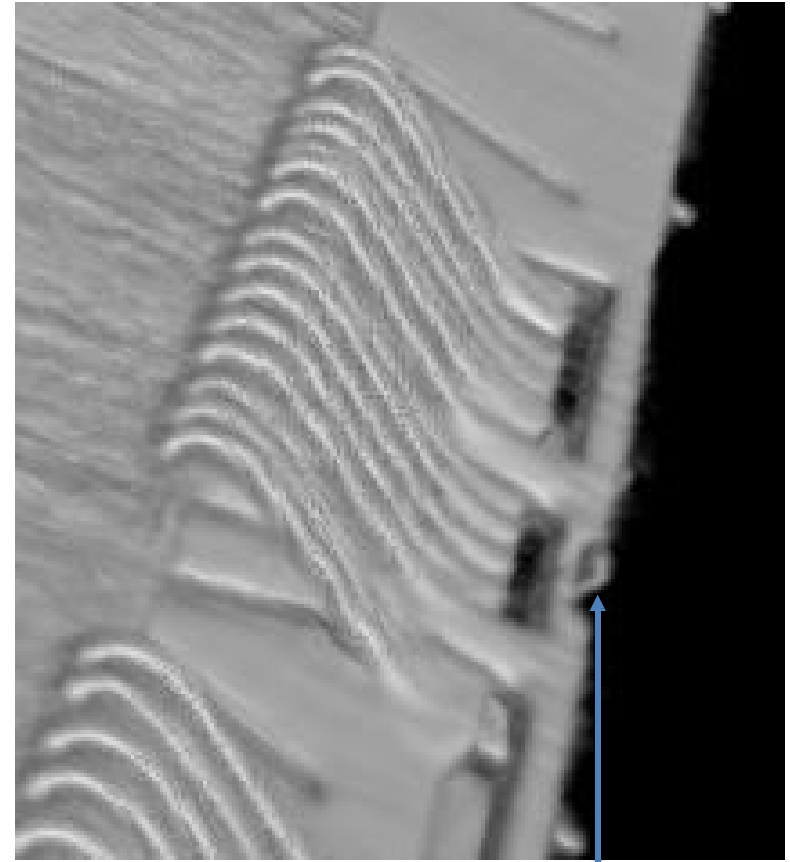
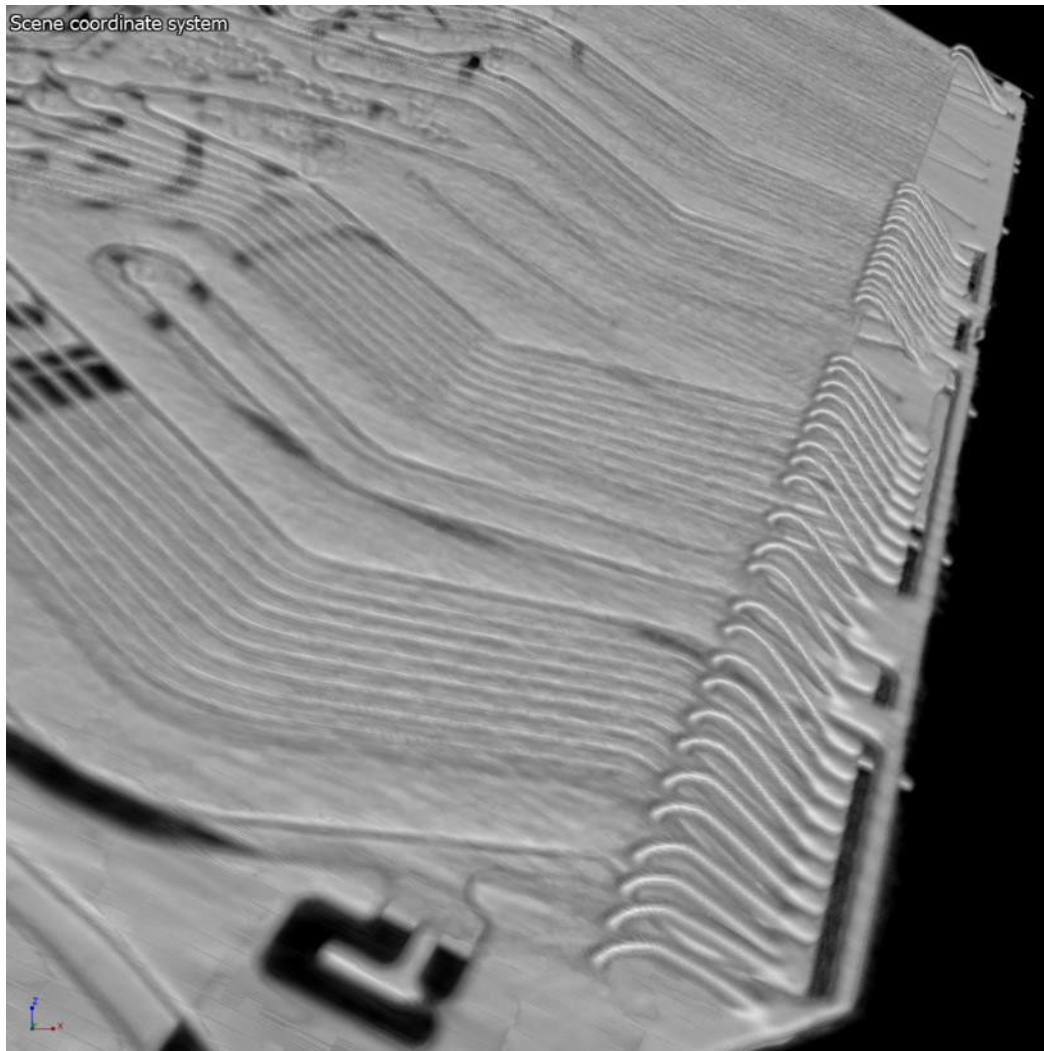
Damage on the substrate



3Dsnap shot of the package.



3 D snap shot of wirebonds on the large die



Damaged line, piece is away from the cu planes, possibly no interplane short circuit

3D view from back side of the package

