Case Study: Radial Cracks in a Rigid-Flex Assembly

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Abstract

Crane Aerospace & Electronics in Redmond, WA, develops, qualifies, and manufactures a variety of implantable devices for leading medical companies. An unusual phenomenon was discovered during a routine visual inspection step on a recent development project. On the flexible portion of a rigid-flex PCB assembly, visible radial cracks were found on the annular rings of ENIG-plated thru-holes. The thru-holes remain unpopulated during Crane's assembly process, and the defect was primarily seen on the top side of the PCB. Additionally, the occurrences of these cracks vary in frequency and severity. This paper describes the testing and analysis Crane performed in order to determine the root cause of this defect.

Key words: corrosion, ENIG, black pad, crack, medical device, PCB, failure analysis

Introduction

The human body is essentially one big electronic black box where groundbreaking research is performed each day to fully define the functionality of our biological circuitry. Scientists have discovered that electrical stimulation may be used to treat autoimmune diseases, neuropathic pain, and loss of hearing. New applications for technology will continue to appear as the design envelope of future medical devices is pushed beyond present day standards.

Even as medical devices continue to change in complexity, size, shape, weight and cost, the expected level of quality will only continue to increase. In this evolving field, designers, manufacturers, and suppliers find themselves drafting and revising numerous specifications and quality standards each year as the underlying technological complexities are improved and becomes better understood.

Over the past year Crane encountered such a challenge during the development of a rigid-flex assembly. Crack-like features that were foreign to Crane, the PCB supplier, and the customer had been discovered on the thru holes in the flexible portion of the assembly. As a result, Crane initiated numerous investigations to understand the phenomena and to determine the root cause. This paper will detail the discovery of the defect, root cause investigations, and the resulting mitigation plans chosen by the three parties.

The Discovery

As with any next generation device, the substrate design limits are among the first factors tested. During an initial prototype build, visual inspection flagged several units for adhesive squeeze out on the annular rings in the flexible portion of the board. PCB specification, IPC-A-600H, section 4.1.2.1, states that adhesive must not encroach within 0.05mm (0.00197in) of a thru-hole. A high magnification measuring scope was required to determine which PCBs exhibited rejectable levels of squeeze out. While examining the affected PCBs for this condition, radial crack features were discovered as shown in Figure 1.

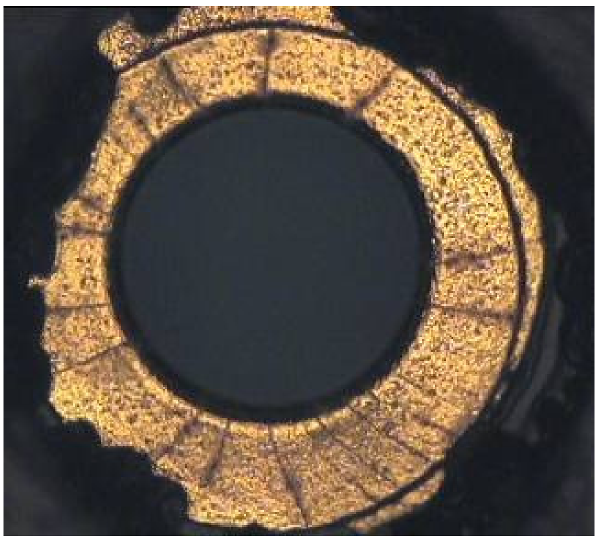

Figure 1 – Photo of severe cracking defect (176x magnification).

The cracks were found to vary in size, shape, quantity, and discoloration. Furthermore, the cracks were only observed on the top side of the board where a mechanical stiffener is adhered.

The discovery of these radial cracks prompted the need to evaluate the flex annular rings and thru holes at a higher magnification than normal IPC requirements for the identification, evaluation, and root cause determination.

Root Cause Analysis

Initial feedback to the client and supplier prompted two sequential experiments at Crane in addition to implementing special screening of the PCBs at incoming.

All incoming lots of PCBs were now visually screened 100%. Several boards were photographed and inspected at 176x using an OGP Smartscope. Figure 2 shows the as-received condition of the board at Crane, confirming the defect is occurring during the PCB fabrication process.

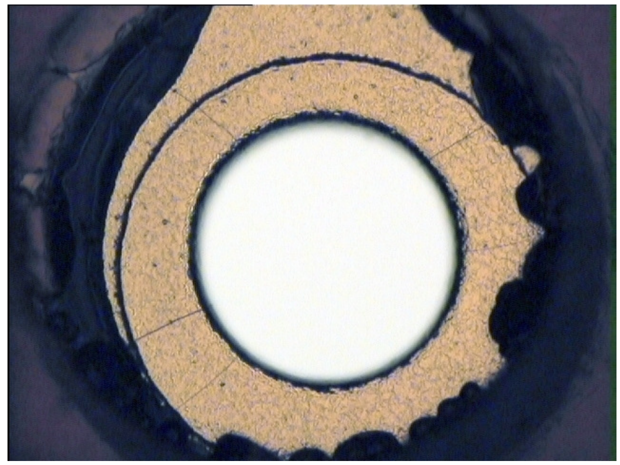

Figure 2 – As-received condition of the PCB, showing visible cracking on the annular rings (~120x magnification)

Given the difference in severity of the defects shown in Figure 2 and Figure 1, it was not clear whether the assembly process at Crane exacerbated this pre-existing defect. Our internal CBS (Crane Business Systems) tools identified several possible causes, and consequently the following actions were planned to learn more about this phenomena:

1. Simulate temperature excursions using bare boards to determine if internal processing exacerbated the pre-existing condition.

2. A second simulation similar to the first, but Polyimide tape was applied over both sides of the flex thru-holes to determine if the tape would protect the existing cracks and minimize the severity of the defect.

3. Perform cross sectional analysis with SEM/EDS of selected samples from both simulation groups to determine how deep the cracks are and how the material composition near the crack varies from the bulk plating.

4. Feed back results to the client and supplier for additional interpretation in order to develop a mitigation plan and solution.

The simulations were designed to ascertain whether thermal stresses created during Crane's internal assembly process would magnify preexisting cracks or create new instances. Processes involving heat exposure occur in the following sequence:

1. Serialization ink cure (30 min at 150℃)
2. Moisture bake-out (7hrs at 125℃)
3. Solder reflow (peak temp ~221℃)
4. Aqueous Clean (wash temp ~65℃)
5. Moisture bake-out (3hrs at 125℃)
6. Solder reflow (peak temp ~221℃)
7. Aqueous clean (wash temp ~65℃)
8. Temperature cycling (10 cycles 25℃ / 125℃)
9. Burn in testing (160hrs at 125℃)

NOTE: Six of the nine processes occur in open air environments; the solder reflows and burn in take place in a nitrogen environment.

During the first simulation nine sample bare boards from three different supplier lots were randomly selected. To establish a baseline, each flex thru hole was photo documented prior to any thermal exposure; pictures were then taken after each solder reflow, temperature cycle, and burn in test. A visual key was created to alphanumerically define the location of each thru-hole per board as shown by Figure 3.

Results from the first simulation visually show all the thru-holes unchanged at ~176x magnification after all thermal exposures (Figures 4 and 5). Although Figure 4 may visually represent a majority of the sample population, there were still numerous instances where a dark residue was found surrounding each crack (Figure 1). Samples already exhibiting this condition appeared to worsen during the simulation (Figure 5).

In an effort to prevent or minimize the spreading of the unknown dark residue a second simulation was performed. The sample population consisted of 18 boards and subdivided accordingly per Table 1. To provide additional information, three sample boards had the tape replaced on both sides prior to the second bake-out and temp cycle test (PCB s/n's have been italicized and underlined in Table 1).

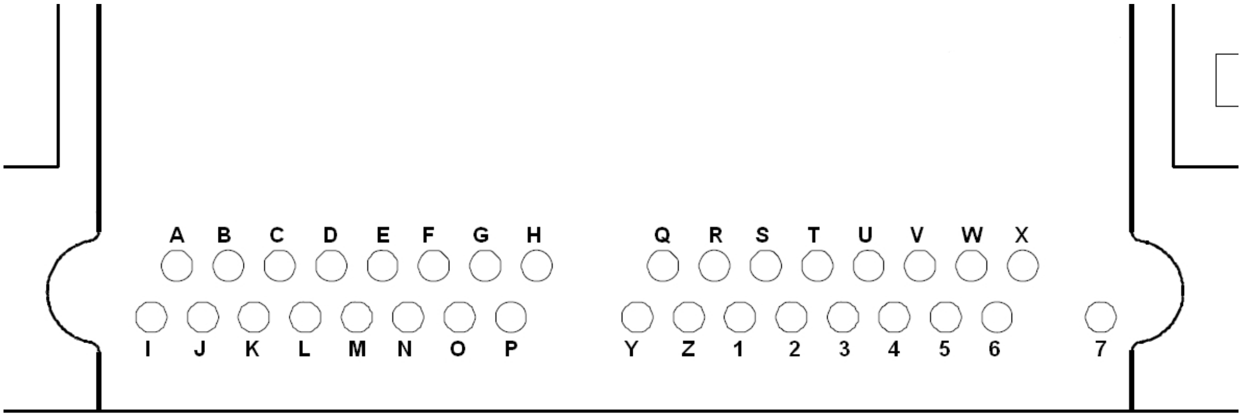

Figure 3 – Alphanumeric visual key used to provide traceability of every flex thru-hole throughout the assembly process.

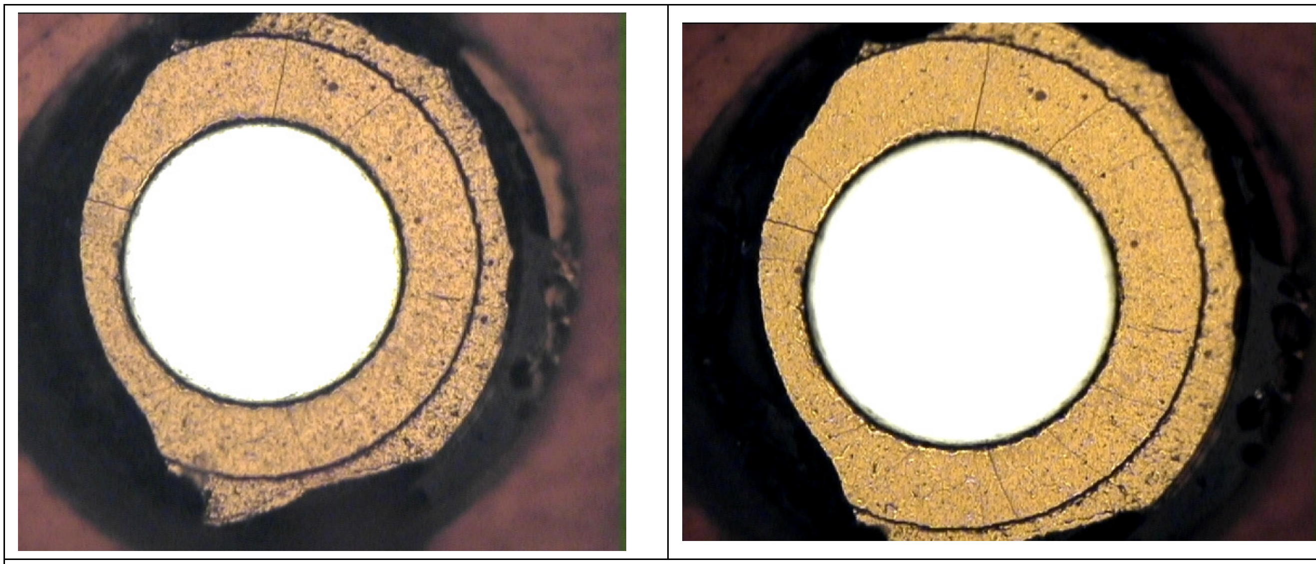

Figure 4 – Condition of flex thru hole at location 2 before (left) and after (right) thermal processing.

Table 1 – Subdivision of sample boards

PCBs without Polyimide Tape		**PCBs with Polyimide Tape**	
Crane LOT #	PCB s/n	Crane LOT #	PCB s/n
1-R5	01-8	1-R5	*04-18*
	03-3		05-5
	04-11		07-12
1-R6	03-12	1-R6	*03-2*
	05-5		03-3
	06-2		03-11
MFG Lot 1	06-1	MFG Lot 1	*06-16*
	06-7		09-5
	06-8		09-9

All 18 samples underwent the same processing and photographs were taken before and after the entire simulation. Most of the annular rings were visually unchanged after testing, but samples with discoloration similar to Figure 1 continued to degrade even when sealed with polyimide tape. On those worst-case samples, the area of discoloration continued to spread during the simulation.

Cross sectional microscopy and SEM/EDS analysis was performed at an independent laboratory. Ten samples were selected from the second simulation experiment for cross sectioning. One sample was further examined using a SEM/EDS before and after cross sectional analysis. Additionally, Crane defined the area of interest and section plane for each PCB as depicted by Figure 5.

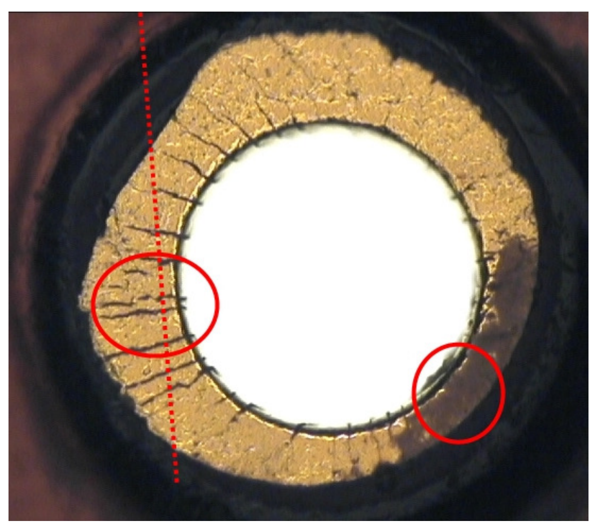

Figure 5- SN06-16-Y, SEM/EDS sample with the cross section plane defined by the dotted line and the desired EDS regions circled.

SEM images and EDS spectra of PCB sample 06-16, location Y, are shown by Figure 6. At the top of this figure two spectrums are superimposed. The blue line correlates to the region inside the blue box of the adjacent image where the gold was analyzed. The red line correlates to the center of the crack feature. At this magnification (472x) both areas were composed of Au, Cu, C, and O. SEM and EDS analysis of the stained region shown by the bottom half of the figure reports Au, Cu, C, O, and Cl. Chlorine is not used during Crane processing, but it may be a byproduct of the plating corrosion.

Next, the region of interest from each sample was removed from the rest of the board, vacuum encapsulated in epoxy and sectioned through the pre-defined planes. Optical examination of these samples revealed that the cracks on each annular ring were actually corroded fissures in the nickel-phosphorus [Ni(P)] plating. Pitting corrosion of the copper layer was also evident in most cases unless the entire Ni(P) layer had been consumed. Sample 1-8, location 7, is an example of this (Figure 7).

Cross sections performed by the supplier early on had only revealed cracks originating from the Ni layer without signs of corrosion occurring yet. This suggested the possibility of a time dependent behavior if residual cleaning chemistry was trapped inside a crevice.

Visually, the gold layer appeared to be completely consumed in regions where the corrosion resulted in a complete fissure through the Ni layer. Full fissure formation was not observed on the bottom side of the PCB, although some corrosion was evident. The lack of uniformity of the corrosion observed between top and bottom sides may reflect on how the PCB panels are processed or handled during fabrication.

SEM and EDS analysis of PCB 06-16 after sectioning at location Y revealed the following composition: Au, Cu, Ni, Cl and P (Figure 8). This figure clearly shows the cracks are actually fissures with the corroded metals from the plating layers growing towards the surface.

Based on both visual and EDS spectra findings the problem appears to be related to the black pad (excessive nickel-phosphorus corrosion) phenomenon. This was further confirmed by EDS analysis of the nickel-phosphorus layer and the black pad region. Ni and P compositions for both layers were 89% and 11% vs. 83% and 17% respectively.

In summary, the following facts were established during Crane's investigations:

1. Fissure growth is being initiated at the supplier during Ni layer plating.

2. Sealing the annular rings with polyimide tape during assembly processing does not minimize or prevent further corrosion.

3. Temperature excursions during assembly processing do not cause a significant change to the appearance of the annular rings.

4. Plating defects consistent with the black pad phenomenon have been confirmed by an independent lab.

Mitigation Efforts

Current mitigation efforts by Crane include 100% visual inspection of the incoming PCBs. All engineers and inspectors that handle product have received IPC-A-600 training and certification.

At the moment, the fissures are not being rejected at incoming or final visual unless they are visible at 40x magnification per IPC-A-600H. The actual effect this condition has on the overall product reliability is still unknown.

Samples from other suppliers have been received with the same fissure defect being found on the top side of the board.

The current supplier has changed the surface finish of the flex from ENIG to HASL after attempts to determine the root cause of the fissures proved unsuccessful. It is still unclear to the supplier how the cracks or fissure structures were initially created. Boards built recently with the HASL finish meet the visual requirements without the concern of black pad occurring.

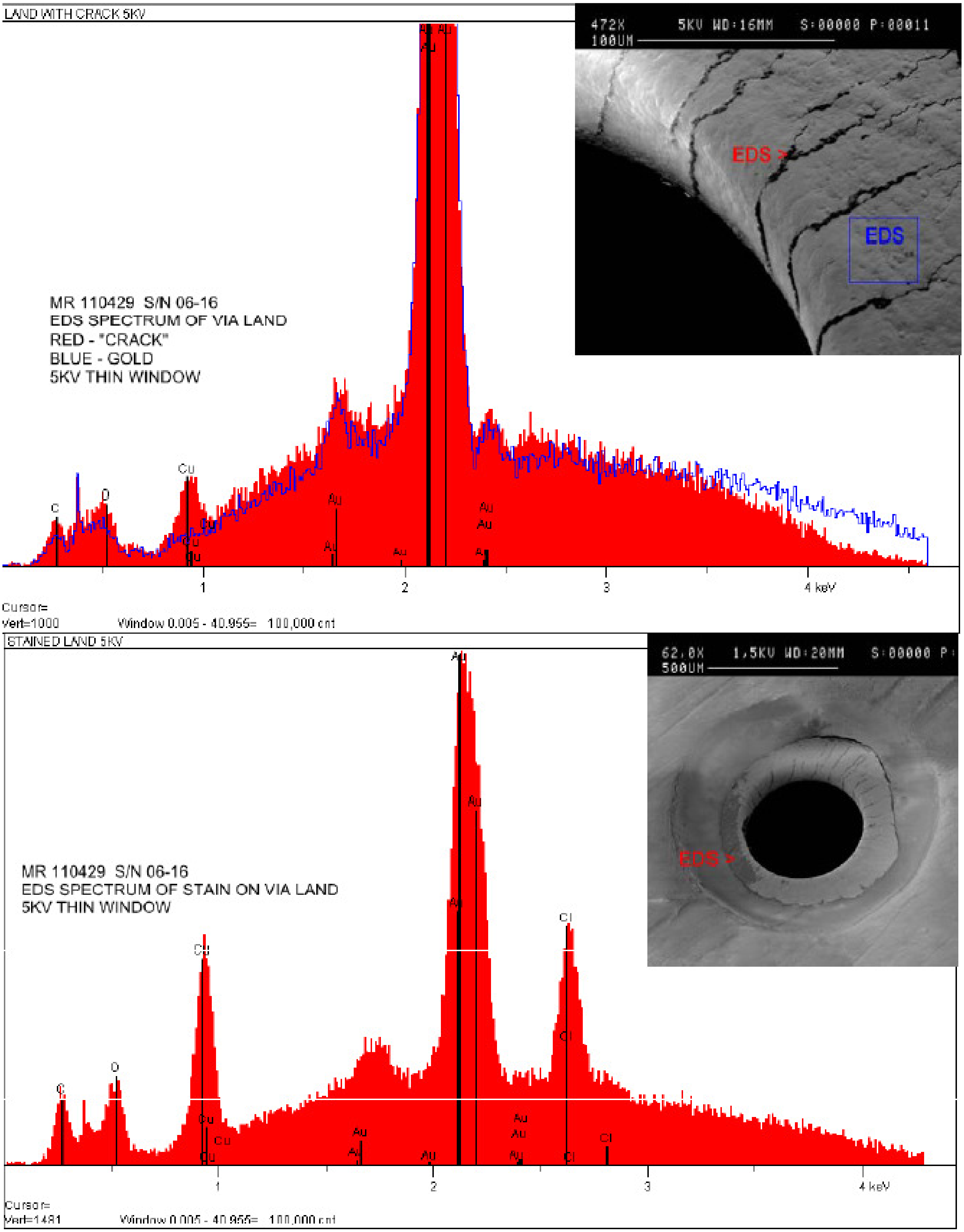

Figure 6 – SEM and EDS spectra of PCB 6-16, location Y.

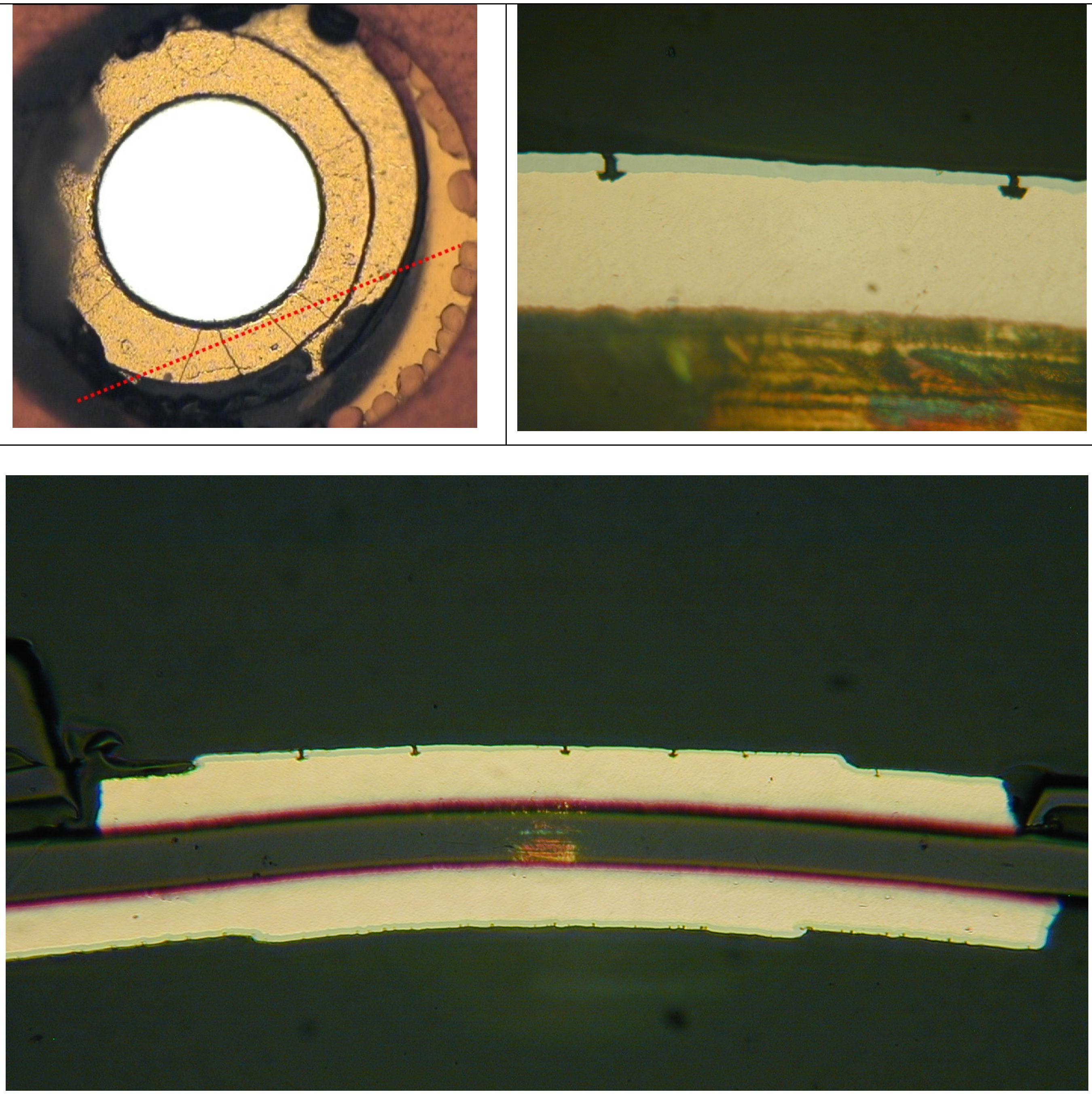

Figure 7- PCB Sample 1-8, location 7

Top Left: Annular ring with section plane pre-defined by dotted red line
Top Right: Sectioned view at 760x magnification highlighting evidence of pitting corrosion
Bottom: 150x view of section highlighting the difference between the opposing sides

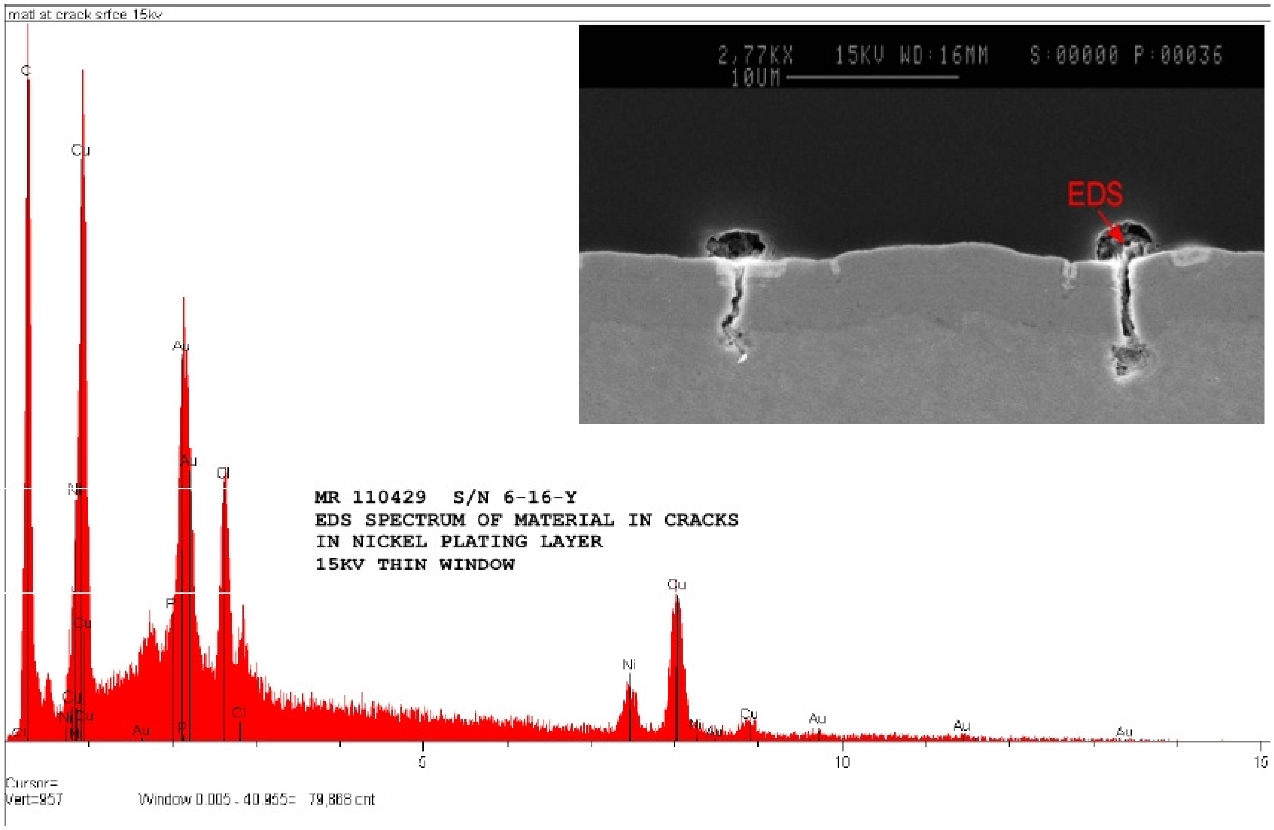

Figure 8 – SEM and EDS spectra of a fissure in PCB 6-16, location Y.

Conclusion

Results from tests conducted by Crane point to the root cause of this phenomena to lie somewhere within the supplier's PCB fabrication process. However, due to cost and time constraints the customer has accepted the use of a HASL finish for the flex portion of the board while maintaining ENIG on the rigid section. In addition, both Crane and the customer are in the process of searching for alternative suppliers capable of supporting this rigid-flex development.

As with any new product development, the probability of encountering unexpected challenges with medical devices is very high. In addition to new problems, mature topics such as black pad may present themselves in unique ways. As new technologies and processes are developed, both suppliers and manufacturers will need to continue investing in education and training their workforce to ensure compliancy and meet the demands of tomorrow's devices.

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