CDF Silicon TASK-Force

1st Report

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bolla@fnal.gov
(For the CDF Silicon Task-Force[1])

Introduction

Since the installation of the CDF Silicon Detector some of its modules failed with unrecoverable symptoms. A fraction of these failures have been categorized as infant mortality. Another fraction instead failed later on during CDF Run2 and the time stamps of the failures are strongly correlated with high and/or anomalous trigger conditions. The CDF experiment decided to form a TASK-Force inside the Silicon group to understand these trigger-dependent failure modes and possibly reduce or remove their rate of occurrence. These failures can be grouped in 2 separate categories:

1. DVDD jumper failure (12 failures out of a total of 360 modules)
2. DOIM failure (2 failures out of a total of 580 modules)

The 2 failure modes have separate symptoms both of them are consistent with the loss of continuity on a power line. These power lines are a series connection of traces in the hybrid and wire-bonds.

Investigation

The initial phase of the investigation ruled out the possibility to fuse the power line locally (either the trace or the wire-bond) in the module due to power surges. Test on the bench showed that the power supply tripping mechanism is adequate to protect the circuit load with a safety margin exceeding 20.

A second phase of the investigation was then started by following the hypothesis that wire-bonds that are orthogonal to the magnetic field are constantly under the effect of Lorentz forces while a current is passing through them. The force applied to the wire-bonds is in the order of the 1-100 mg depending on the current and wire-bond length and clearly not large enough to break a healthy connection.

In the case of the DVDD Jumper failure mode the current flowing through the wire-bonds is not constant with time but it depends on the state of the BE (Back End) of the SVX3d chips and the frequency with which the current changes is a direct consequence of the trigger conditions (L1A-DIGITIZE-READOUT cycle).

[1] The work of the CDF Silicon TASK-Force is accessible on the web at www-cdf.fnal.gov/upgrades/silicon/TASK-Force/main.html

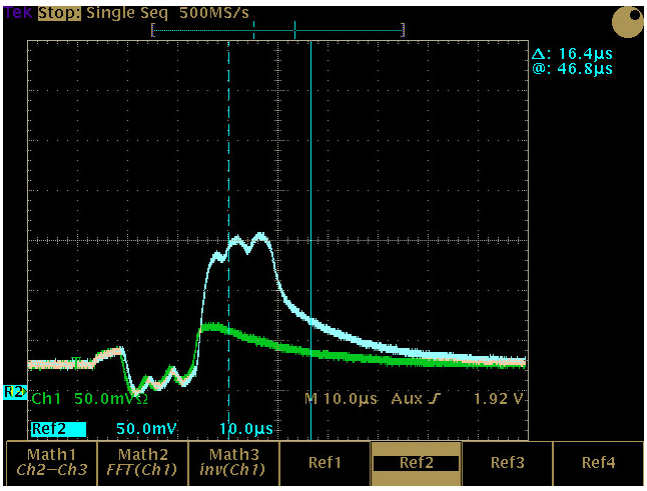

Figure 1: Current versus time in the DVDD jumper connection during a L1A-DIGITIZE-READOUT CYCLE. The current probe is set so that **1 mV** corresponds to **1 mA**. The GREEN curve is measured while stopping the readout at the end of the last PHI chip. The CYAN curve is measured while all the 6 chips in the ladder (3 PHI and 3 Z) are read out in read-all mode

The natural resonant frequencies of the wire-bond were calculated by treating it as a violin string. For the wire-bonds of the shape and length as in the case of the DVDD Jumper connection the calculations gave resonant frequencies in the 10-40 kHz range that is well inside the L1A rates achievable by the CDF Silicon detector (the specification for CDF RUN2 is a maximum L1A rate of 50 kHz). A new line of investigation was started to investigate if wire-bonds with current-versus-time behavior similar to what is happening in the CDF Silicon modules can resonate.

The DVDD current through the JUMPER connection (the Jumper connection is usually wirebond-JumperVia-wirebond and it is here replaced with a discrete wire so that a current probe can be placed around it to do the measurement) is about 20 mA in quiet time and it grows during digitize to then go negative while the PHI chips read out and then go back up to 145 mA toward the end of readout. Finally at the end of the cycle the current returns to the quiet state around 20 mA. The behavior can be seen in Figure 1.

By using an AWG (Arbitrary Waveform Generator) and a current amplifier test bonds resembling the ones of the CDF modules were pulsed in a magnetic field of 1.4 T at various frequencies with various current versus time signals. Resonant frequencies were found in the ranges predicted by the calculations. (A small movie with a wire-bond resonating can be found on the web at www-cdf.fnal.gov/upgrades/silicon/TASK-Force/line3/wtext.mpg).

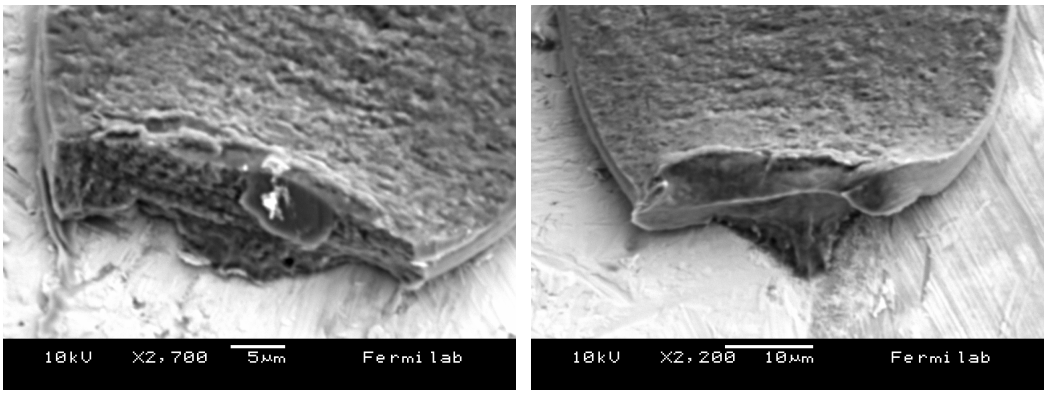

Figure 2: SEM pictures of broken wire-bonds. The one on the right shows the breakage for a bond that has been broken by the pull test while the one on the left shows a bond that broke as a consequence of the oscillations induced by the Lorentz forces. A more detailed explanation of these pictures can be found

Wire-bonds that are continuously pulsed at a resonant frequency break at the heel in a time scale of minutes. In figure 2 a wire-bond broken with this technique is compared with a wire-bond that has simply been pulled. The difference of the breakage surface is very visible. The resonated wire-bond shows a brittle surface with a fatigue line in the middle while the pulled bond shows a complete ductile surface. Figure 3 shows a SEM picture of a bond that has been resonated but the procedure was stopped before breaking it. The wire itself is clearly cracked at the heel as a consequence of the induced vibrations. A more detailed explanation of these SEM pictures can be found on a 1991 IEEE paper (IEEE TRANSACTIONS ON COMPONENTS, HYBRIDS, AND MANUFACTURING TECHNOLOGY, VOL. 14, NO. 4, DECEMBER 1991) that is also available on the web at www-cdf.fnal.gov/upgrades/silicon/TASK-Force/line3/Brittle-Cracks.pdf.

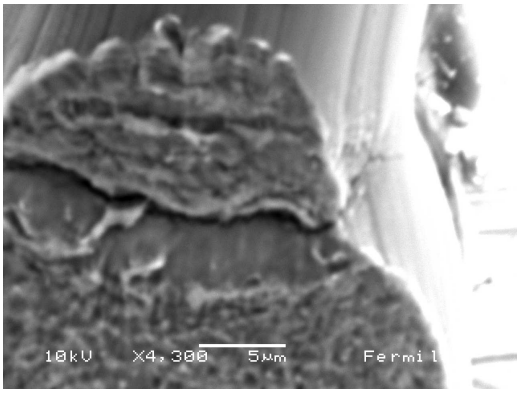

Figure 3: SEM picture of a wire-bond that as been resonated in the magnetic field and still provide electrical continuity. A crack is visible.

Conclusions

Permanent failures of the CDF Silicon Detector are explained by wire-bonds breaking due to fatigue stress on their heel induced by resonant vibration. These resonant vibrations are a direct consequence of the oscillating Lorentz forces induced by the magnetic field on wire-bonds with non-DC current. The CDF Silicon TASK-Force is pursuing a set of tests with the primary goal to lower and/or eliminate the failure rate and

to prolong as much as possible the lifetime of the detector. A more general analysis of the topic is being pursued as well with the goal of understand if changes in the packaging and assembly processes for future applications can be done in order to avoid the failure mode.