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Failure analysis of the MimoSTAR3 prototype

Device description

The device under investigation is MimoSTAR3 - a pixel sensor fabricated in a 0.35 µm processes with 2 poly layers and 4 metal layers.

The device is composed of a 640 x 320 array of pixels with readout electronics located at the bottom of the chip. Pixel size is 30 µm x 30 µm and the total sensor size is approximately 2 cm x 1 cm. The floor-plan view of the device is presented in Figure 1.

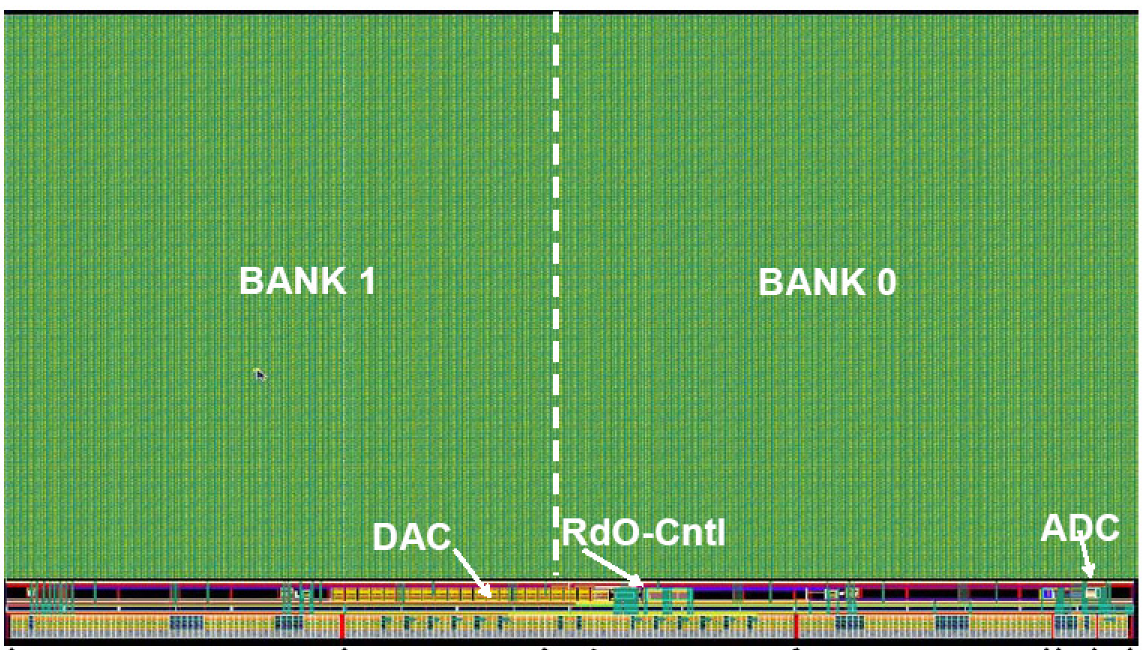

Figure 1 Floor-plan view of the tested sensor

Failure

MimoSTAR3 has a very low fabrication yield. Most of the pixels in the central areas of all tested sensor are non-functional. It appears possible to explain the observed behavior as a contact problem with one or more of the vias described below. The only functional pixels are located in a very narrow ring at the edges of the pixel array.

Analysis goals

The goal of this study was to check for connection failures at the in-pixel vias by looking at cross sections through the critical nodes. The critical vias were assumed to be related to the connection of the power supply to the forward biased diode and the connection of the signal to the input of the source follower transistor.

Schematic diagram in Figure 2 shows a pixel cell with the vias analyzed in this study.

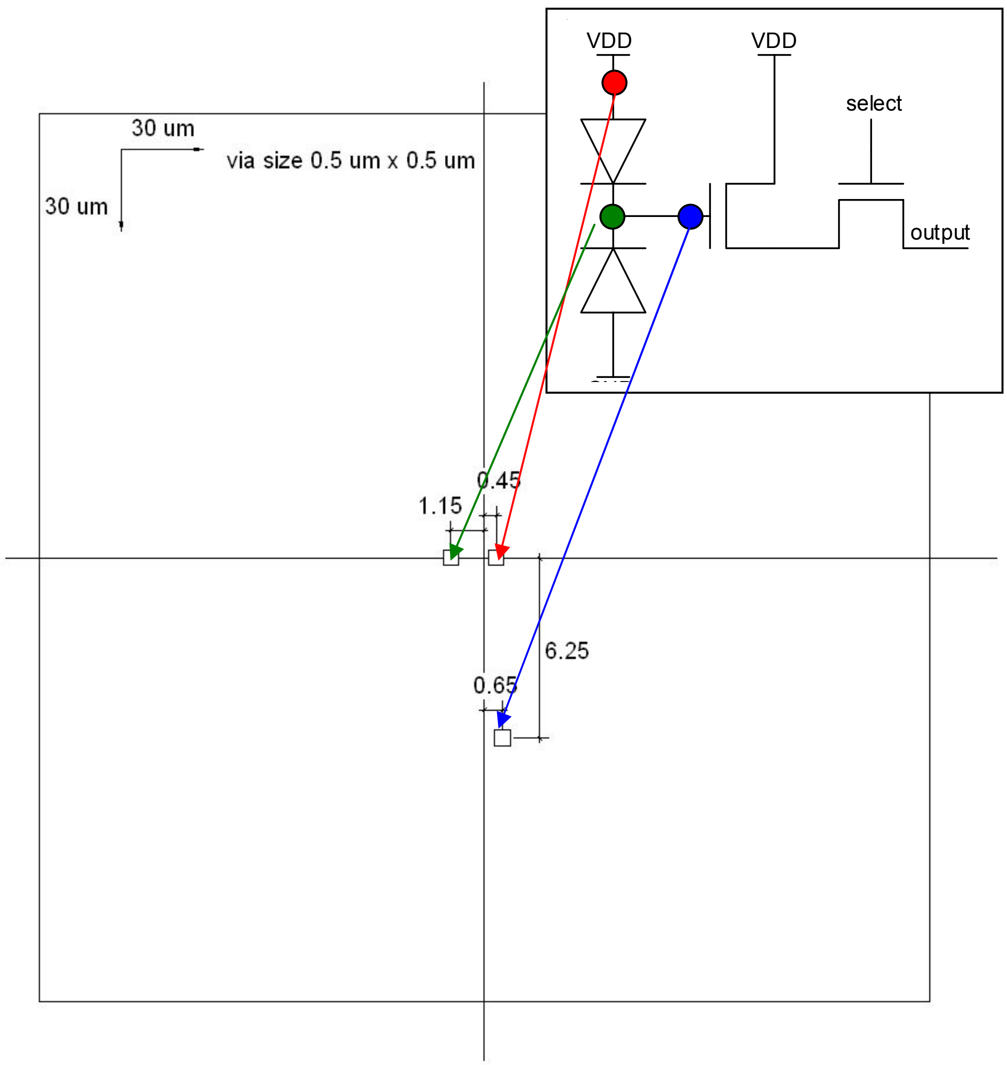

Figure 2 Schematic diagram of a pixel cell (only vias of interest are shown) and the related nodes on a pixel functional schematic.

We chose two cross-sectional views as presented in Figure 3 with the following requirements:

1) Section through the two vias located near the center of the pixel and aligned on a horizontal axis of the pixel. The cross-section view should be at least about 10 um wide.
2) Section through the two vias about 0.5 um to the right from the vertical axis of the pixel. One via is located on the horizontal axis of the pixel and the second via is about 0.65 um lower. The cross-section view should be at least about 15 um wide. (The cut can be either parallel to the vertical pixel axis or it can be angled to pass through centers of both vias at the same time.)

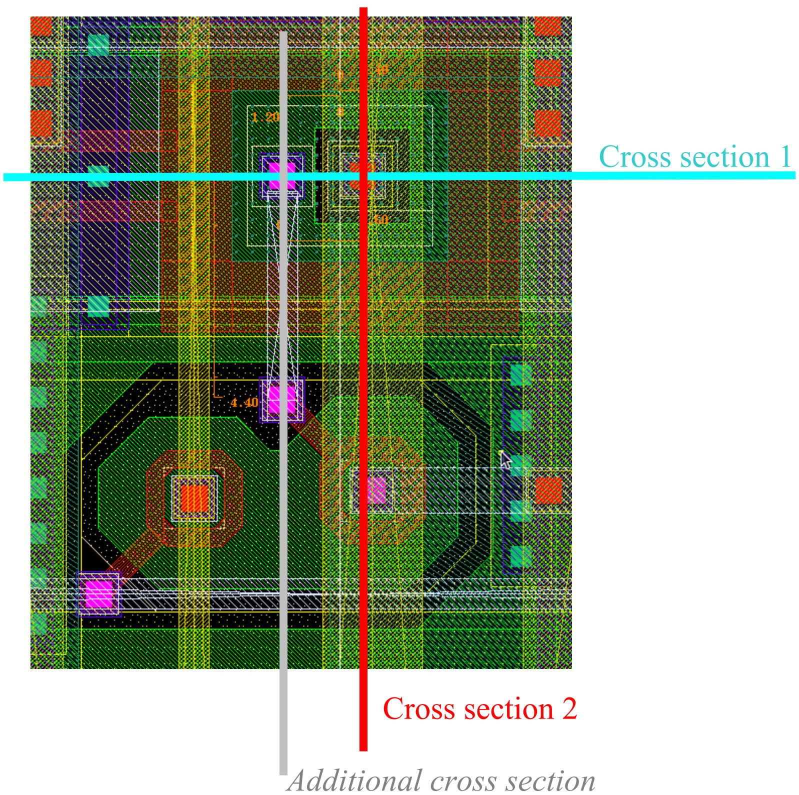

Figure 3 The two cross-sections of interest (cross section 1 and 2). The *additional cross section* is one of slices that will be presented in the section "Results".

The two types of cross-sections are not compatible in the scope of one pixel. Therefore, the total of four cross-sections requires looking at four pixels – two operational and two faulty.

Pixels from an operating area (boundary) of the sensor and pixels from the presumed faulty region (center) were chosen for the comparative study. The pixel regions of interest are presented in Figure 4.

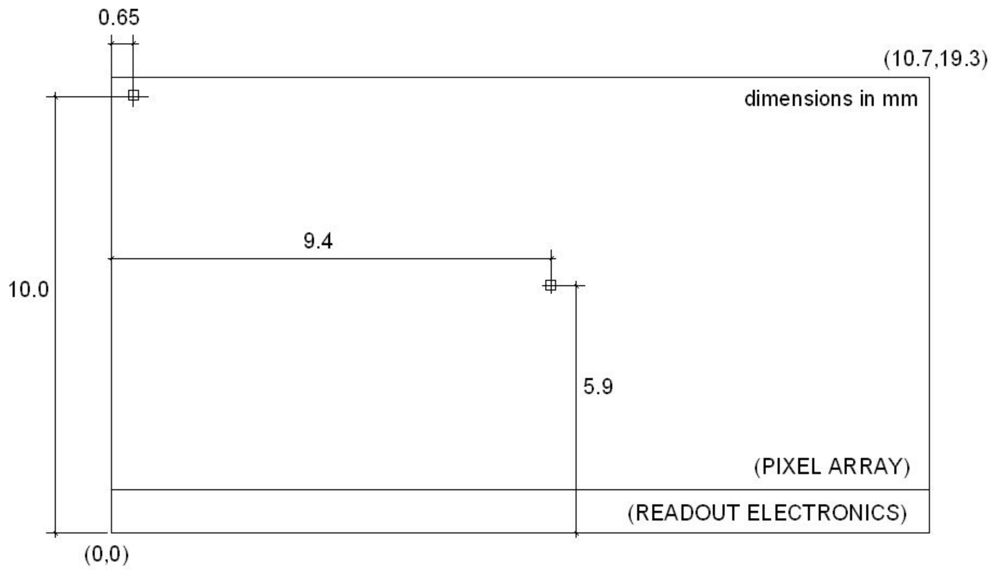

Figure 4 Areas of interest chosen for the study of connection failures in MimoSTAR3.

Results

We engaged Nano Integrated Solutions, Inc. (formerly FIB International, Inc.) located in Santa Clara, California. This company provides a large selection of failure analysis and debugging services mainly targeted towards the electronic industry. This includes a service and consulting for testing and failure analysis (FA) of microelectronic devices with Focused Ion Beam (FIB) technologies.
The setup for the Focused Ion Beam analysis can handle samples smaller than 25 mm x 25 mm and less than 10 mm thick. Both bare dies and bonded dies can be analyzed.

We started with a bare and untested die. A fallback option was to glue a MimoSTAR3 sensor with a wafer grip adhesive, characterize pixel operation, and remove the sensor from the test board before sending it in. The results presented below show that the more complicated fall back option is not needed.

The costs for the works described here were at $500 per cross section and $150 for each additional slice. For each cross section, we requested 2 additional slices to obtain better insight into the possible failure modes by looking at the depth of the cross section.

An example of the multi-slice cross sectioning is shown at company's web page at http://www.fibinternational.com/sliceandview.avi

We have received 66 pictures of MimoSTAR3 cross sections within a week from sending our sample. Below are selected pictures that highlight the connectivity problems on the MimoSTAR3 sensor. The complete set of pictures is accessible at:
http://rnc.lbl.gov/hft/hardware/docs/mimostar3_cross_sections/1/index.html
http://rnc.lbl.gov/hft/hardware/docs/mimostar3_cross_sections/2/index.html
http://rnc.lbl.gov/hft/hardware/docs/mimostar3_cross_sections/3/index.html

The image presented in Figure 5 shows the surface of the pixel before performing a cross section cut. The pixel area is clearly visible. The groups of vias 7x7 correspond to vias in the corners of the pixel as presented in the layout. The two dips in the center of the pixel correspond to the rectangular areas of vias. The pad visible in the center of the pixel is a layer of Platinum deposited on the top of the sample before the cross section is done to preserve the top surface.

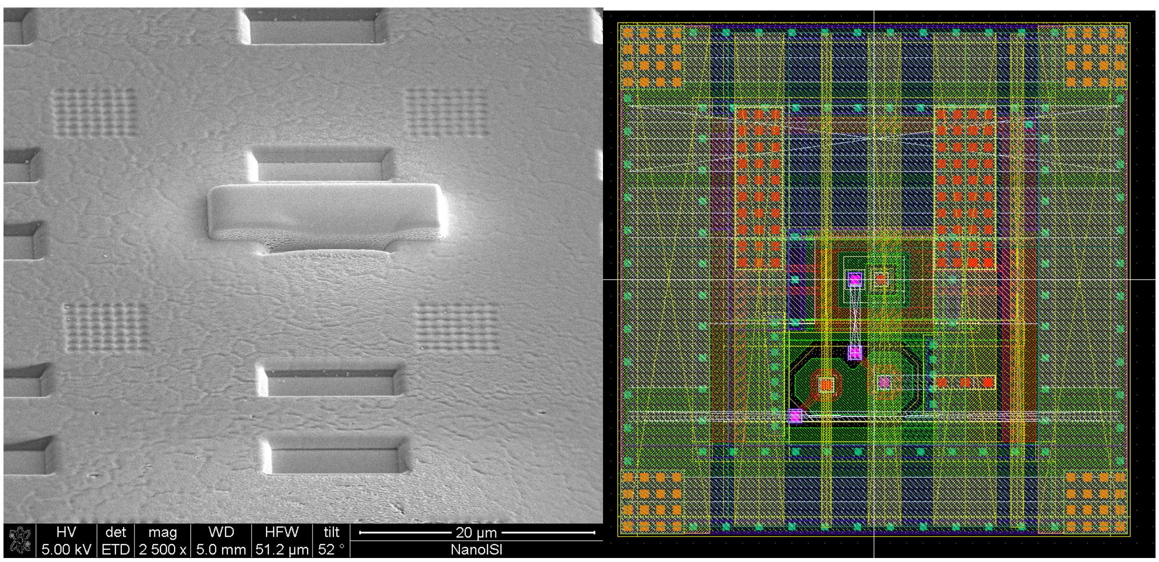

Figure 5 The image of the pixel area and the layout of a single pixel. Note that the picture is rotated by 90 degrees with respect to the layout view.

Figure 6 presents a cross section through layers on the top of the charge collecting diode. The forward biased diode is connected to the trace in the metal_3 layer. The connection between the n-well and the source follower transistor is implemented in the metal_2 layer.

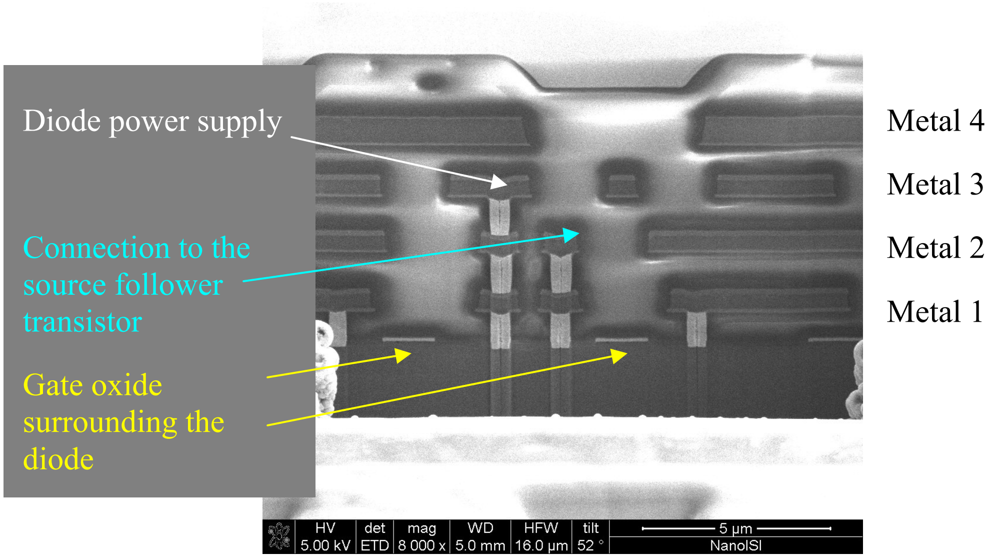

Figure 6 A cross section through layers above the n-well region.

A comparison between the same via sets in the pixel from the boundary and from the center of the pixel array is presented in the following figures:

- Figure 7 – cross section 1
- Figure 8 – the *additional cross section* from Figure 3.
- Figure 9 – cross section 2
- Figure 10 – close up of typical vias from the boundary and the center of the pixel array

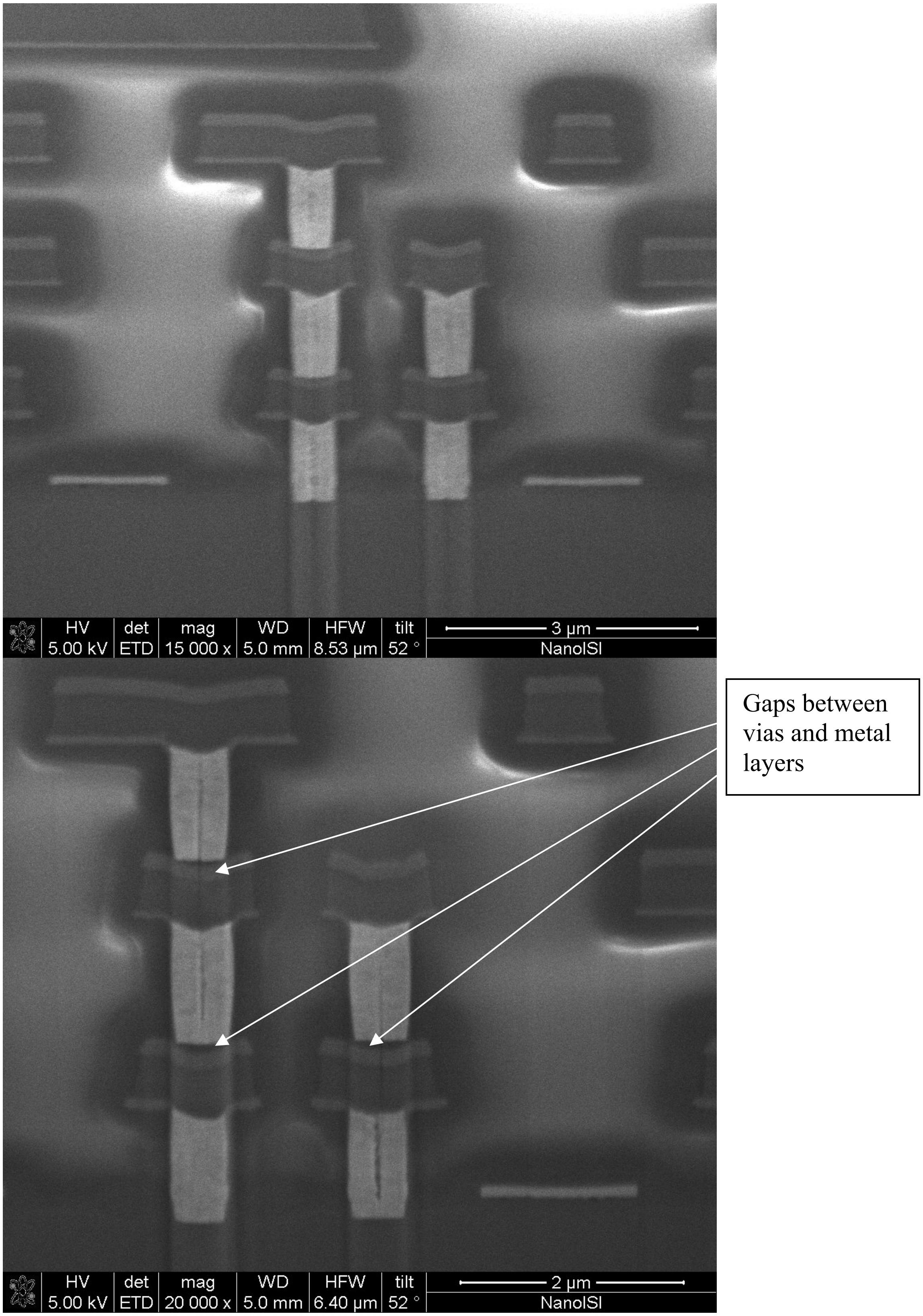

Figure 7 Cross section 1 through vias connecting the power supply to the forward biased diode (left stack) and the charge collecting node with the source follower transistor (right stack). Upper image – pixel from the corner of the sensor, bottom image – pixel from the center of the sensor.

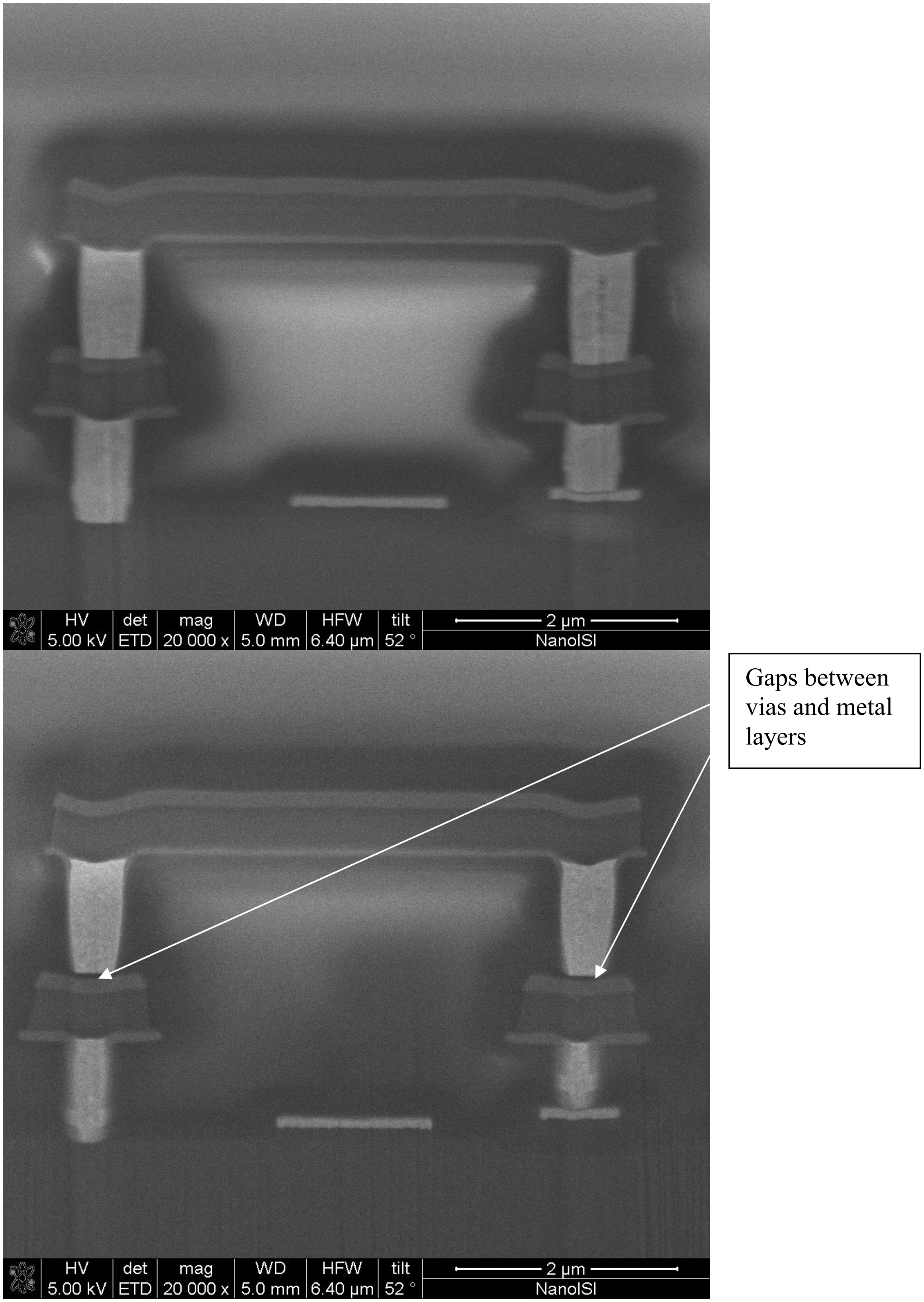

Figure 8 The *additional cross section* through vias connecting the charge collecting node (left stack) with the source follower transistor (right stack). Upper image –pixel from the corner of the sensor, bottom image – pixel from the center of the sensor.

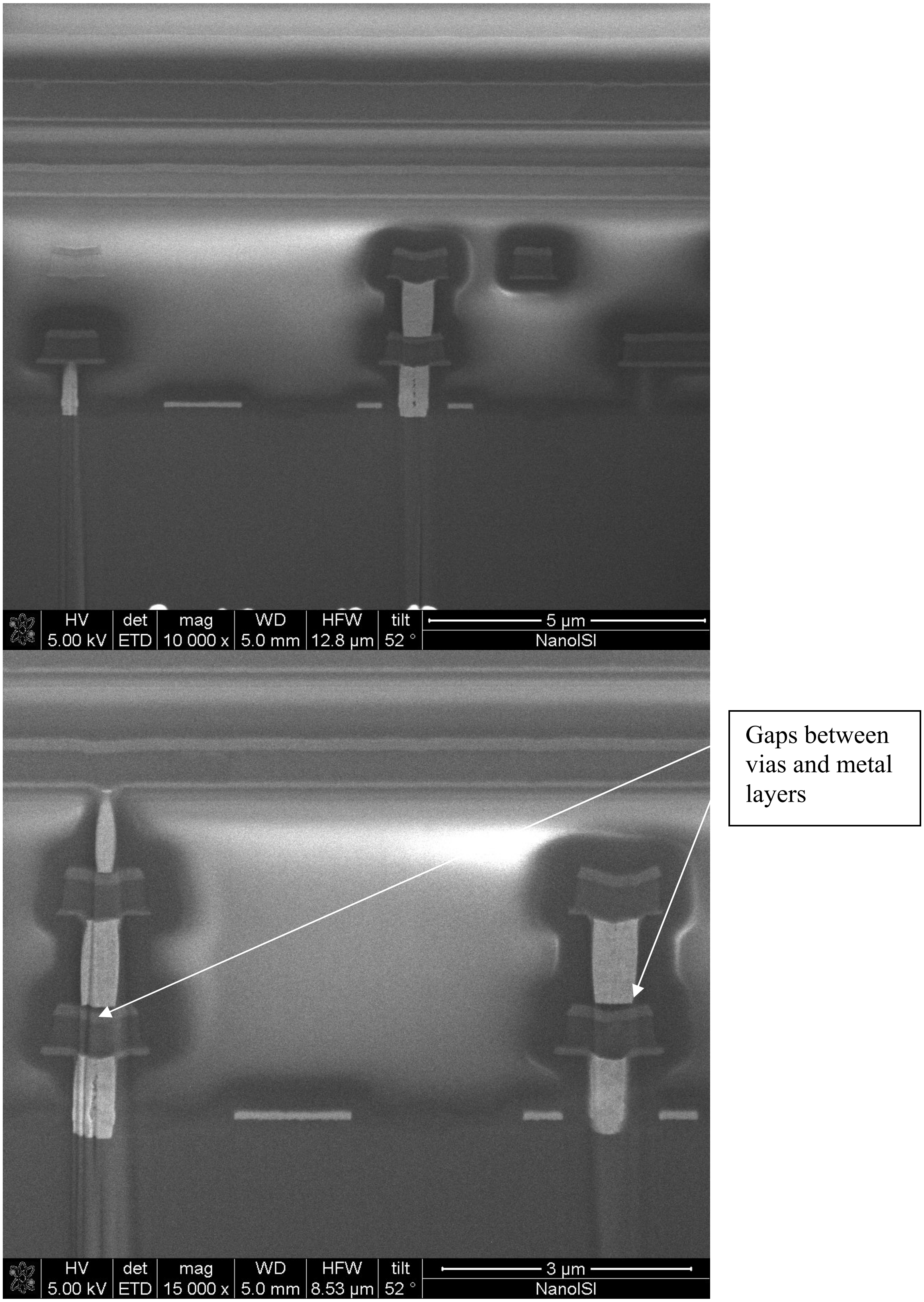

Figure 9 Cross section 2 through vias connecting the power supply to the forward biased diode (left stack) and the charge collecting node to the input of the source follower transistor (right stack). Upper image –pixel from the corner of the sensor, bottom image – pixel from the center of the sensor.

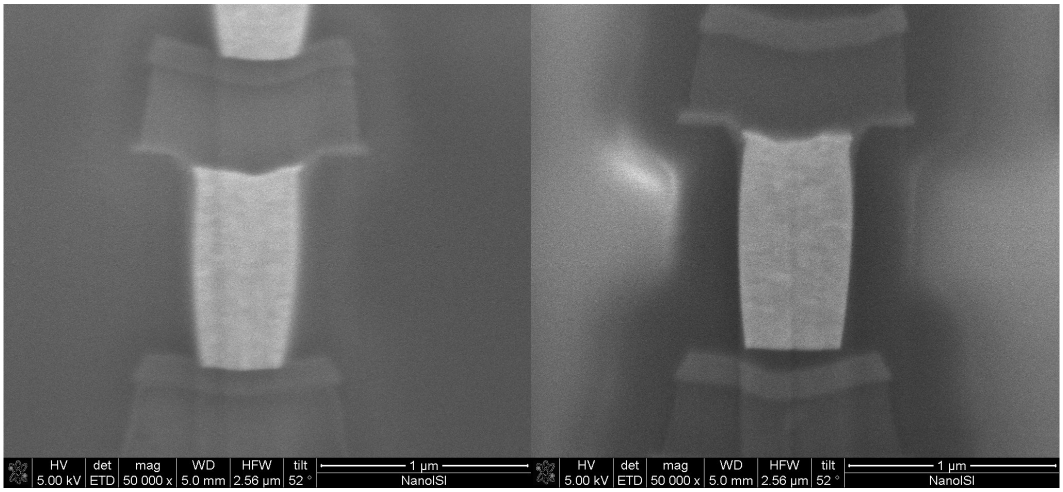

Figure 10 Close up of typical vias from the boundary (left) and the center (right) of the pixel array. The gap between the via filling and the metal layer is clearly visible in the center of the pixel array.

Summary and Conclusions:

The pictures presented in this document show clearly that the MimoSTAR3 prototype suffers from faulty vias in the center of the pixel array. The problem seems to affect most of the vias that can be seen in the cross sections studied. The affected vias are between the layers of metal_3 and metal_2 as well as metal_2 and metal_1. All vias between metal_1 and gate oxide or diffusion/implantation regions look correct. The cross sections presented in this document did not contain any vias between metal_4 and metal_3.
In addition, a measurement taken from the pictures in figure 10 shows that the via lengths appear to be equal, but the spacing between the metal layers appears greater in the pixels in the center of the sensor as compared to the pixels in the periphery of the sensor.

The conjectured cause of the problems observed in the MimoSTAR3 has been confirmed to be faulty vias. We hope that it will help to understand the origin of the problem and allow us to resubmit a re-engineered MimoSTAR3 that will address the observed problems and demonstrate full functionality in the scaling of the designs to near reticule size sensors.