APPLICATION NOTE

Multi-channel EBIC on 7nm technology node: revealing hidden signals

In collaboration with

point electronic GmbH

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ABSTRACT

Electrical Failure Analysis (EFA) is critical for ensuring quality and reliability of semiconductor devices. As the architecture of advanced technology nodes grows more complex, localization and understanding of electrical failures become more difficult as well. Intricate three-dimensional structures, overlapping fields and mixed sources of contrast make analysis on advanced semiconductor devices a challenging task.

In this application note, we show how multi-channel nanoprobing, color-coding and signal math can make the EFA workflow for advanced technology nodes more straightforward, with a 7 nm technology node transistor as an example.

SETUP

- Imina Technologies Nanoprobing platform with 8 NANO+ nanoprobers
- point electronic GmbH EFA system with in-situ amplifiers
- Tescan Clara SEM

SAMPLE

7 nm CMOS device delayered to contact level

INTRODUCTION

One-channel nanoprobing has been the standard approach to EFA until recently, however, advanced chip designs with overlapping structures and complex electrical interconnects make it difficult to distinguish between different sources of contrast, such as Electron Beam Induced Current (EBIC), Electron Beam Absorbed Current (EBAC), and Electron Beam Induced Resistance Change (EBIRCH).

Multi-channel approach to nanoprobing and EFA removes some of this complexity from the data interpretation, introducing intuitive color-coding of the signals either by nanoprobe, or by current direction. The advanced EFA setup presented here is designed so that each prober has an independent parallel routing and amplification, producing 8 independent live images.

The raw images can be combined in different regimes, nanoprobe- and current-coding.

- Nanoprobe-coding: each live nanoprobe image is assigned a monochrome palette that progresses from black at lowest pixel value to a probe-unique color at high pixel value. Then all individual live images are mixed into a live multi-color view of the nanoprobed device.
- Current-coding: each live nanoprobe image is assigned the same color palette, with negative current coded in red, zero current in black and positive current in blue. Current-coding is possible thanks to calibrated gains and offsets in amplification and digitization that are now used to calculate current in each pixel value.

In addition to the qualitative color mixing, calibrated gains on each channel enable quantitative measurement of current polarity and value in each pixel. This capability, in turn, opens a possibility to perform quantitative image math.

Image math is important, as it enables the user to separate overlapping signal originating from the device under test, for example currents from overlapping fields. This capability is very useful when characterizing small transistors of complex architecture like the 7 nm technology node.

Let's consider a few examples.

IDENTIFYING NETS

In this first experiment, acceleration voltage is set to a low value such that only EBAC currents are produced in the interconnects, without reaching the active areas underneath and therefore avoiding EBIC currents. Nanoprobes are landed on the network of interconnects to collect currents at different probing points, and device bulk is grounded to divide the EBAC current according to relative resistances, and therefore to provide strong Resistance Change Imaging (RCI) contrast for the probed interconnects.

Three live probe images are acquired, and a sequential black-to-color palette is assigned to each of the signals. Sequential here means that a brighter color corresponds to a larger quantity. Blue, red, and green are selected for the nanoprobes in this example. Live images are mixed with the gray Secondary Electrons (SE) image, to produce a live color view of interconnects, as shown in Fig. 1.

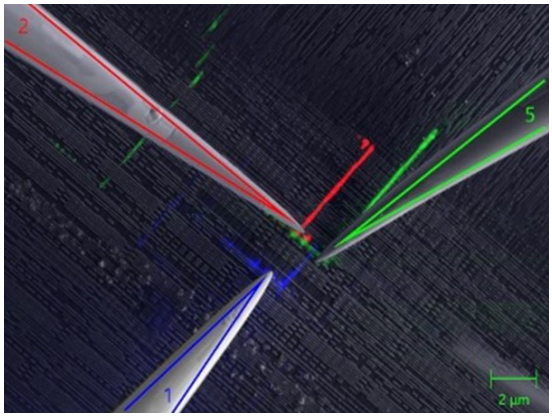

Figure 1. *Large-scale interconnected nets of 7 nm technology node circuit revealed with color-coded nanoprobing.*

Fig. 1 is a live probe color view, with gray signal providing general information about surface topography and near-surface layers, and blue, red, and green highlighting the interconnect lines electrically connected to each nanoprobe. Brighter color indicates a lower resistance path to the respective nanoprobe, as is standard Resistive Contrast Imaging (RCI), but now in live color.

Assigning different colors to each probe, the user can map multiple nets at the same time, both close to the nanoprobes, and away from them. Using multiple nanoprobes at low magnification is a very effective way to map out and navigate up to 8 separate networks on one sample, even far away from the landing points.

MAPPING ACTIVE AREAS

In the second experiment, we image active areas of an individual transistor. We land the probes on Gate, Source and Drain, with the device's bulk separately connected to the Ground. The acceleration voltage is set to a higher value so the electron beam can reach active areas underneath the interconnects. Electrons from the beam generate EBIC currents in the transistor active areas, while the EBAC currents in the interconnects are smaller than in the previous example. As the beam scans the device surface, several currents originating from different active areas are picked by the nanoprobes, complicating the interpretation of the measurement.

To simplify this analysis, every nanoprobe image is colored with the same red-to-black-to-blue palette, with red corresponding to negative currents, black – to zero currents, and blue – to positive currents. This palette is called divergent, as it starts with black from the middle and highlights two different kinds of signals, i.e. negative and positive currents. Divergent palette helps intuitive perception as it keeps the zero current as black, and equal current values of opposite signs, e.g. -10 pA and 10 pA, have the same intensity of red and blue, respectively.

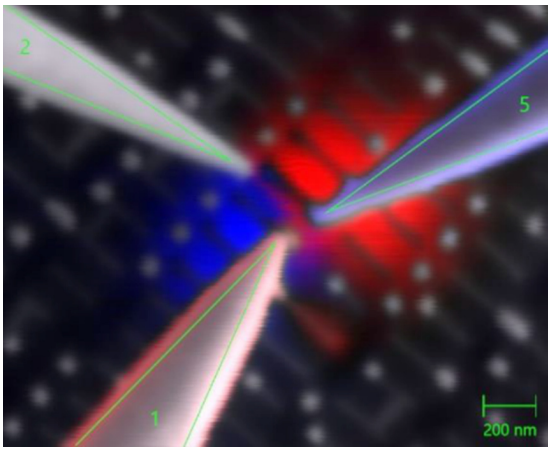

Figure 2. *Source and drain active areas of a 7 nm node transistor revealed with current-coded nanoprobing.*

Fig. 2 shows how all collected color nanoprobe images are mixed with the gray SE image.

Source and drain active areas of the transistor are revealed intuitively in the same image, in red or blue, reflecting current polarity. Brighter colors denote stronger fields of increasing current collection, and the broadening corresponds to the minority charge carrier diffusion. This is standard EBIC, now in multiple colors, without the need for multiple scans or different images to display multiple active areas.

There is, however, the third field in the transistor missing from this view – the isolation field underneath the entire transistor. To reveal it, we need to take the next step to image math.

REVEALING HIDDEN FIELDS

Color mixing corresponds to summing the simultaneously acquired images in Red, Green and Blue (RGB) channels. This is possible because the palettes are quantitative, in the sense that a brighter color represents larger current. In other words, the same result will be obtained by adding the measured currents from all nanoprobes, and then applying the divergent red-to-black-to-blue palette. Color mixing is therefore just one case of image math, and other image math operations are available, for example to reveal hidden currents.

One may think that the currents measured in the source and the drain nanoprobes should be identical, as the EBIC contribution is the same for both. If so, subtracting the two currents should produce an image without contrast. However, a small EBAC current is always added to the larger EBIC current, and subtracting the two nanoprobe currents instead reveals this EBAC contrast. Furthermore, subtracting the source current from the drain current will reveal not only the EBAC current, but also any additional hidden current contribution that may be present in the device. If this contribution is small, it will not be readily observed in the larger EBIC current, and it will only show after subtraction.

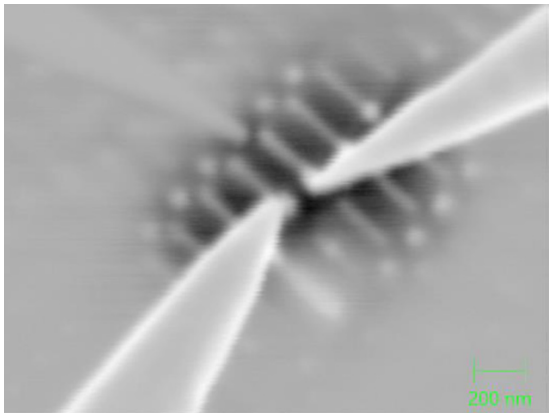

Figure 3. *Isolation field of 7 nm transistor revealed by subtracting drain current from source current.*

Fig. 3 shows image subtraction on the dataset shown above, presenting only the hidden current. It shows nanoprobes, device surface and layers, and an additional weaker field.

This is explained as electron-hole pairs generated in the Source and Drain areas are separated and collected not only laterally in the transistor, but also vertically. The isolation field gives rise to an additional small current path going to the device bulk connected to ground. This current is removed from the total EBIC current, so it cannot be seen in an image sum, but is easily revealed with an image subtraction. Current to the isolation field can also be measured by connecting device bulk to an additional signal input, instead of ground, and directly imaging the respective current (not shown here).

CONCLUSION

This application note shows how live color-coded EFA transforms the workflow for advanced technology nodes, as we show here with an example of a 7 nm technology node CMOS transistor.

Color-coded EFA is enabled by a new generation of signal acquisition and processing hardware featuring calibrated amplification and parallel imaging of all nanoprobe signals. Imina Technologies' nanoprobing setup works in synergy with point electronic's EFA module, with a fully integrated workflow.

Live color-coded EFA makes the workflow more intuitive and easier to interpret, at the same time enabling more complex analysis not accessible previously. With live color-coded EFA, it is easy to visualize interconnected circuits across the sample (probe-coded), and to understand the EFA signals, e.g. based on currents flowing in different directions (current-coded). Thanks to calibrated amplifiers, image math with subtractive color mixing is also possible, revealing otherwise hidden sources of signal.

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REFERENCES

Advances in EFA with Color Coded Multi-Channel Nanoprobing, Paper No: istfa2023p0427, pp. 427-431; 5 pages, Grigore Moldovan; William Courbat; Jörg Jatzkowski, https://doi.org/10.31399/asm.cp.istfa2023p0427

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