COLOR VOLTAGE CONTRAST: A NEW METHOD OF IMPLEMENTING FAULT CONTRAST WITH COLOR IMAGING SOFTWARE

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Abstract

Although voltage contrast and fault contrast methods are well established, the current methods of implementation are frequently tedious.[1,2] A new method of mapping voltage contrast (VC) images in a qualitative (stroboscopic) color mode allows multiple logic states to be simultaneously viewed and updated in color. A shortcoming of image subtraction is that only one direction of logic change is represented unless the frames are exclusive OR'ed together. Although this gives fault information it does not include the VC of neighboring unchanged nodes. When tracking failures such as a saturated transistor resulting from a logic short somewhere else, all logic states; both static and transitional need to be understood and viewed simultaneously if an expedient analysis is desired.

Implementation involves digitally capturing the SEM VC image into all 3 color channels of a digitizer board. The resulting image will be stored except for the color channel selected to continuously receive the live VC image. If the red channel is chosen any nodes which experience a logic transition will affect the red channel as follows: A node which switches from +5 to ground will illuminate red. A node which switches from ground to +5 will lose red becoming aqua (blue-green) in color. Nodes which do not switch will remain represented in black and white respective to their VC bias. Color represents a logic state change with the specific color identifying the direction of transition.

Image Integration and Beam Scan

Image integration is accomplished with a monochrome integrating 768X494 pixel CCD camera using the RS-170 video format. The camera is placed in front of the SEM slow scan screen in order to capture the VC and/or CCVC events. A 12.5 mm TV lens with adjustable aperture is used to control the exposure. The camera eliminates the problem of compatible scan rates between systems and serves as the image integrator. Integration allows noise averaging during video capture for rapid scan imaging resulting in greatly improved VC images from the SEM as well as capture of transitional events under oxide (CCVC). Since the scan and integration rates can be independently controlled, rapid scan rates appropriate for CCVC can be captured and compared to VC images if desired. The equipment required is a VC capable SEM or e-beam prober, a high resolution black and white CCD integrating camera with lens and aperture, tripod camera mount, RGB digitizer board, computer and software. The camera allows direct capture from the SEM screen regardless of scan rate. Photos 1 and 2 illustrate the dramatic difference in signal to noise ratio based on integration.

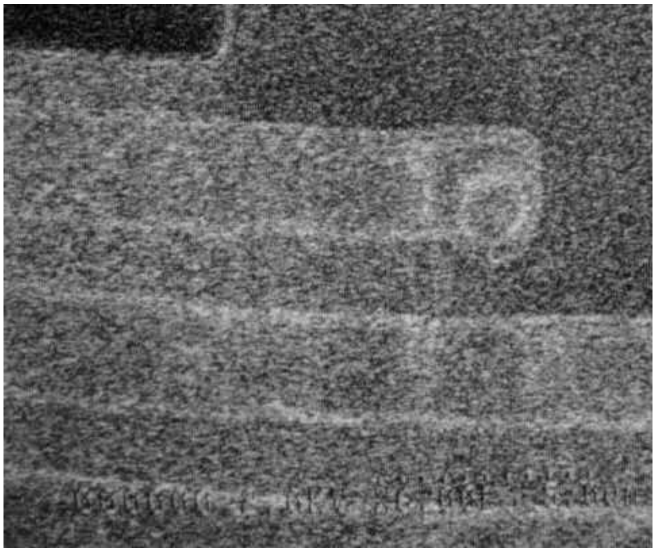

Photo 1 Image obtained from the SEM screen with a camera integration rate of 1/2 a second.

Photo 2 Same image obtained from the SEM screen with a camera integration rate of 10 seconds.

The equipment used in this paper consists of a Hitachi S-2500 SEM, An Alpha Innotech Emission Microscope Workstation (FA1000) for camera and software control of ColorVC, and a chopper circuit for logic state control.

Color Convergence Alignment

A difficulty associated with fault contrast is the comparison of a reference part to a failure. When parts are substituted in the SEM, alignment becomes an issue. Alignment is simplified by using the image from the previous part stored in the blue and red channels to allow a convergence alignment with the new part through the green channel (Or any combination of color channels). Digital zoom is used to allow real-time (1/30 second per frame) alignment of the image.

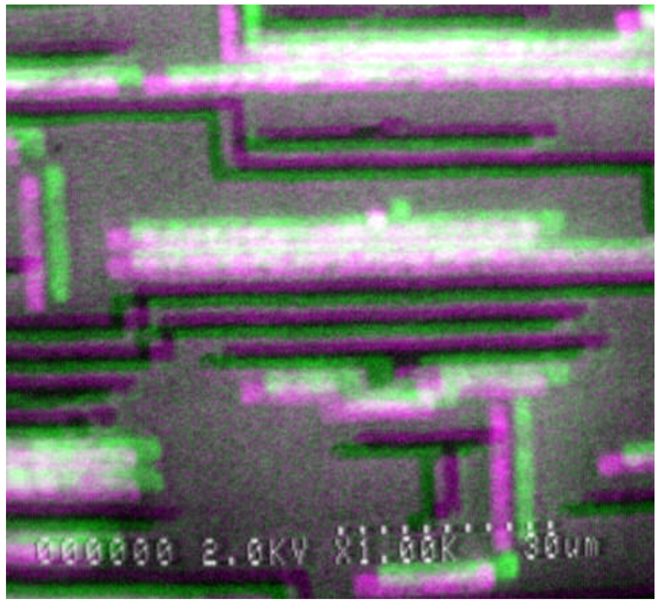

Photo 3 Color convergence alignment in progress utilizing the green channel. Alignment is correct when the image is converged and no color is seen.

Once alignment is achieved the entire image will be black and white. The software can be used to XOR, subtract, or display ColorVC for comparison between the reference and failing parts.

Color Voltage Contrast

Conventional VC reveals information as to the bias potential difference of conductors. The technique is normally implemented with passivation removed and accelerating voltages of 2KV or less[3], however, imaging is possible with passivation at higher beam energies due to the conductive interaction volume generated by the electron beam.[4]

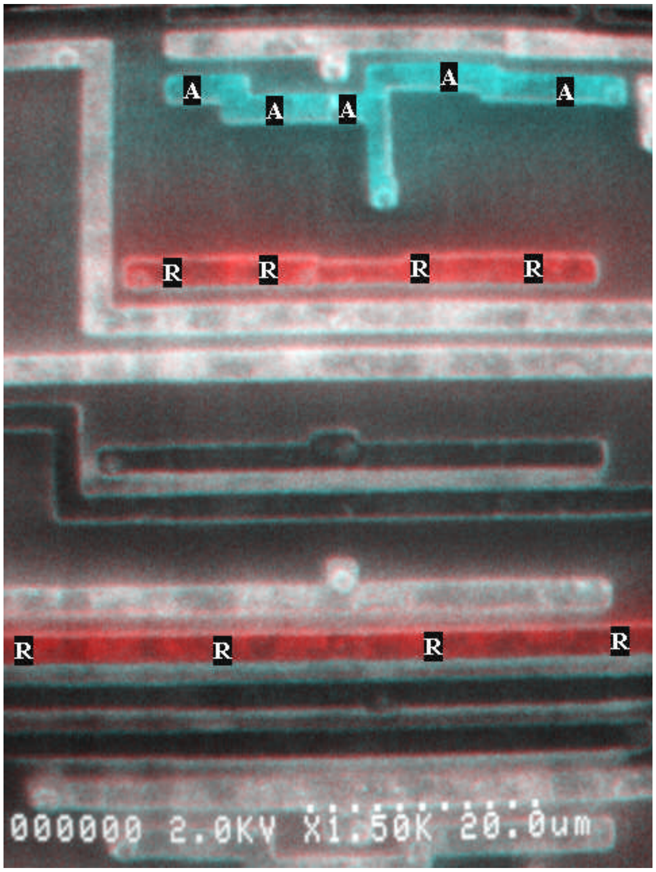

Photo 4 ColorVC image generated after reset transition to low on red channel.
Color Legend: R - red, A - aqua.

A conductor at ground potential will release more secondary electrons than a conductor at +5 volts resulting in a contrast difference in the secondary electron image.[5] ColorVC is accomplished by storing the static VC image information in 2 of the 3 primary color channels and acquiring VC information into the third channel. Photo 4 is a ColorVC image generated by the following steps:

1. Store the VC image with the reset pin held high in the blue and green channels.
2. Acquire the current VC image through the red channel only. At this point a black and white image will be seen since all 3 color channels contain the same information.
3. Switch reset low.

At this point, nodes which experienced no logic change are still represented as white = ground and black = +5. Nodes which are aqua colored are the result of a loss of red when reset was switched low. These nodes are now at +5. Nodes which are red are a result of a gain of red when reset was switched low. These nodes are now at ground. This is the simplest form of ColorVC.

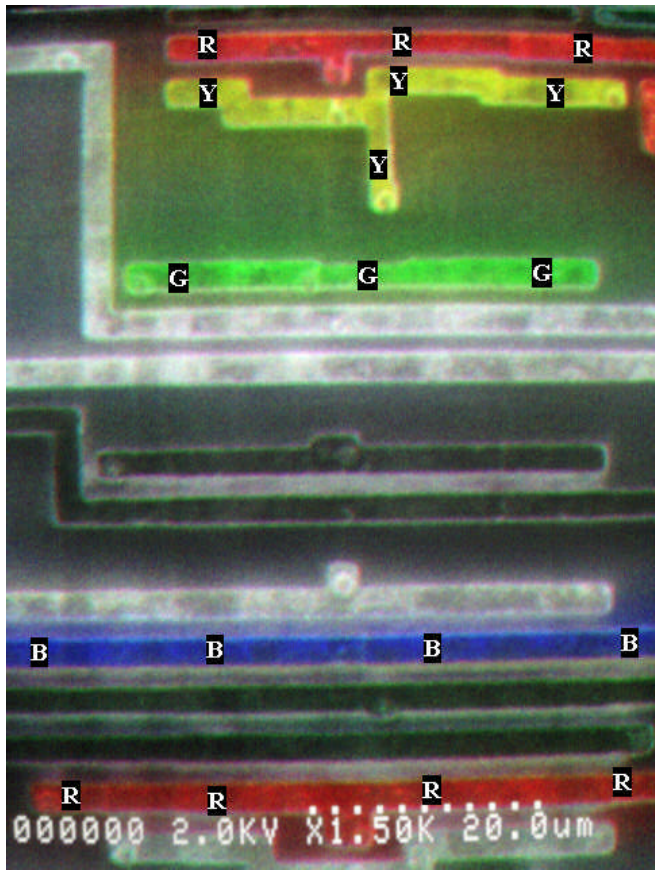

Photo 5 ColorVC image generated with 3 independent logic states stored on each color channel. Color Legend: G - green, Y - yellow, B - blue, R - red.

Two or three color channels can be used to represent sequential changes in logic by changing color channels at key points in the logic algorithm or by loading three different logic states into the three channels as shown in photo 5.

The resulting colors are generated by the following steps:

1. The red channel is loaded with the VC image while reset is high and chip select is low.
2. The green channel is loaded with the VC image while reset is high and chip select is high.
3. The blue channel is loaded with the VC image while reset is low and chip select is high.

Nodes which are red represent a logic transition to ground only when reset is high and chip select is low. Nodes which are green are a result of a logic transition to ground only when reset is high and chip select is high. Nodes which are blue are a result of a logic transition to ground only when reset is low and chip select is high. The yellow node is a result of a logic transition to +5 only when reset is low and chip select is high. Notice that yellow is a result of green and red minus blue.

Color Capacitive Coupling Voltage Contrast

Conventional CCVC allows conductors under oxide to be imaged due to the capacitive coupling of the electron beam and underlying conductor.[6] If the underlying conductor experiences a logic state transition, the surface equilibrium of the oxide will be locally changed. The beam scan will restore equilibrium as a function of time and energy imparted to the affected area. As implied, the scan area, beam current, time, and oxide thickness affect the decay time of the event. Dynamic imaging is accomplished by toggling an input or control pin of choice as shown in photo 6. The resulting CCVC image information can be enhanced dramatically by using ColorVC methods as shown in photo 7. Understanding the generation of the color is important for maximizing the given information. In this case, the blue channel contains the initial logic state information of chip select high. The red channel contains the logic state information of chip select low. The green channel is then assigned to the camera and chip select toggled at 20 Hertz.

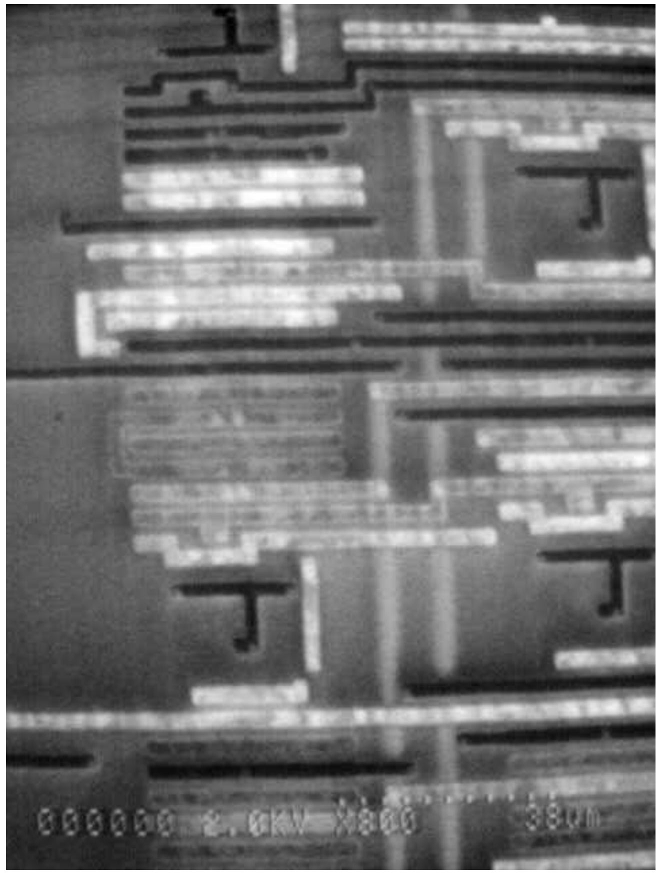

Photo 6 Conventional CCVC image captured in rapid scan mode on the SEM with a 2 second integration rate. Note the visible metal 1 nodes under oxide traveling vertically.

Since the red and blue channels contain different fixed logic state information, green cannot appear in a dc mode. Therefore anything green must be capacitively coupled to the underlying metal 1. Orange can only occur on metal 2 as a result of a combination of red and oscillating green. The duty cycle will affect the hue between yellow and red. Light blue can only occur on metal 2 as a result of a combination of blue and oscillating green. Again, the duty cycle will affect the hue between blue and aqua (blue-green). Two floating metal 2 nodes drift and in this case show up as dark green.

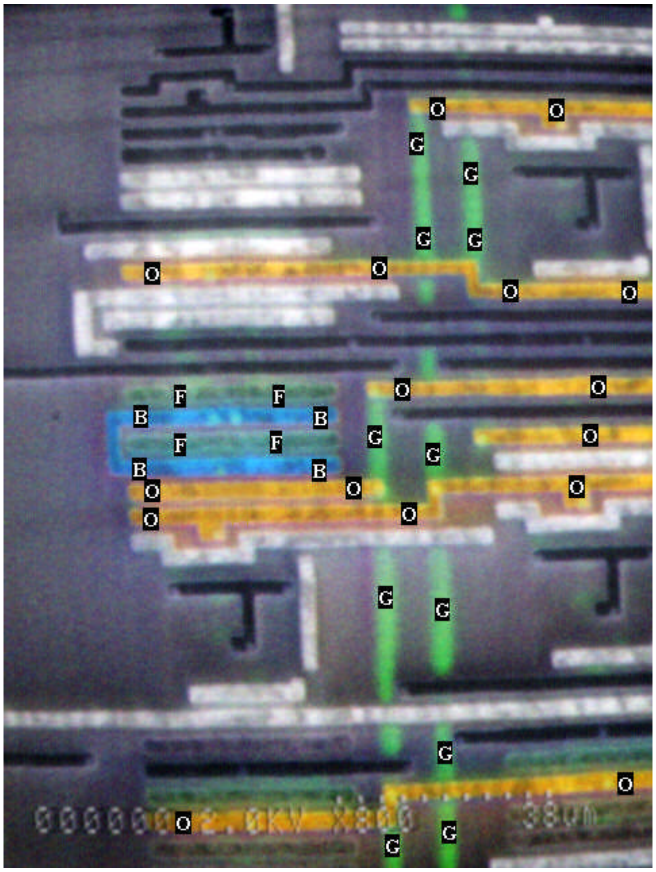

Photo 7 Color CCVC image captured in rapid scan mode on the SEM with a 2 second integration rate. Color Legend: G - green, O - orange, B - aqua+blue, F - floating node.

Low magnification comparison of reference and failing devices is accomplished with color convergence alignment and ColorCCVC techniques. Color regions clearly show the logic difference. The advantage of ColorCCVC is shown in photo 8. Unfortunately, a black and white publication does not do justice to the visualization of color against black and white. Since alignment is dynamic with the color channel being used, slight misalignments due to magnification can be compensated for interactively, revealing only the difference information in color. Any combination of color channels can be used to generate logic state information as well as discriminate capacitively coupled layers.

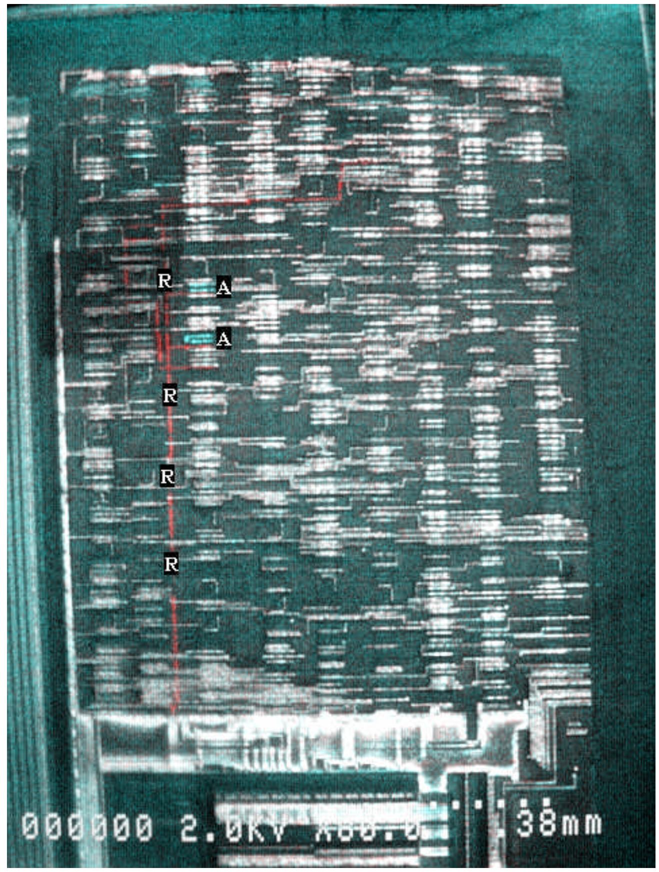

Photo 8 Color CCVC image captured in rapid scan mode on the SEM with a 2 second integration rate. Note the visible metal 1 node under oxide traveling vertically in red. Aqua colored nodes are labeled A. Magnification 80X.

ALTERNATIVE METHODS

Commercially available e-beam testers and digital scanning electron microscopes are quite capable of image integration for stroboscopic voltage contrast. Pseudo color fault imaging is also available in some cases, however, live color voltage contrast imaging needs to be added to the list of diagnostic capabilities. The system must be able to update the selected color channel in a "live" video mode and allow zoom and pan to work in the same fashion.

CONCLUSIONS

A new method to map static and dynamic voltage contrast in color has been presented. Color Voltage Contrast allows nodes in transition to be mapped in color while simultaneously maintaining the original logic states in black and white. Imaging happens real time allowing logic states to be stepped and tracked interactively. ColorCVCC allows analysis of AC signals since color can be used to represent duty cycle as well as discrimination of underlying layers.

Acknowledgments

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5. IBID, p. 165.

6. IBID, p. 166,167.