

A NEW TECHNIQUE TO RAPIDLY IDENTIFY LOW LEVEL GATE OXIDE LEAKAGE IN FIELD EFFECT SEMICONDUCTORS USING A SCANNING ELECTRON MICROSCOPE.

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Abstract

Numerous papers have been written regarding SEM microscopy techniques. The SEM has and will continue to have a stronghold in the semiconductor industry as an imaging and diagnostic tool. This paper will discuss a new application of the SEM for diagnosis and determination of gate oxide leakage via electron beam charge accumulation. Special fixturing or feedthroughs are not required since the E-beam supplies the biasing to the device. Concomitantly, the technique can be used nondestructively for determination of gate oxide integrity failure on wafers in fabrication. This technique utilizes the phenomenon of Electron Beam Induced Voltage and is referred to as Passive Voltage Contrast.

Introduction

"Although voltage contrast was one of the first phenomena observed in the SEM (Knoll, 1941), it remains one of the most important techniques available for the analysis of complex circuits (Gopinath et al., 1978)".¹ Voltage contrast, as the name implies, is an observed contrast differential associated with differential surface potential. Voltage contrast is more accurately described as field contrast since the localized electric fields are actually responsible for the trajectories of the secondary electrons.² The typical SEM employs a scintillator which is positively biased for the purpose of collecting secondary electrons from the specimen. The intensity of stimulation at the scintillator and subsequent magnitude of the photomultiplier signal is a function of the quantity of electrons striking the scintillator. Therefore, secondary electron current or yield is being measured and displayed as the primary beam scans the sample. A conductor which is biased negatively appears bright due to an increase in the secondary electron yield. A positive bias will conversely result in a reduction in the secondary electron yield. Additionally, the secondary electron current is influenced by surface texture, surface composition and tilt angle.

The key to Passive Voltage Contrast is to use a combination of tilt angle and low accelerating beam voltage in order to increase the secondary electron yield of the grounded conductors above the yield for non-conductors (oxides).

Development and Implementation

Figure 1 illustrates the $1/\cos(\theta)$ relationship between secondary electron yield and angle of the electron beam normal to the sample surface for biased conductors. This effect is easily observed associated with bond wires. "The edges of the wire are brightly outlined by the glancing incident beam".³ Non-conductors or electrically isolated conductors are poor sources of secondary electrons since the surface will charge to stable equipotential with a low energy incident beam regardless of tilt angle. Therefore, increased tilt angle will accentuate the difference between oxides or floating gates to that of conductors such as diffusions or compromised gates which have a path to ground.

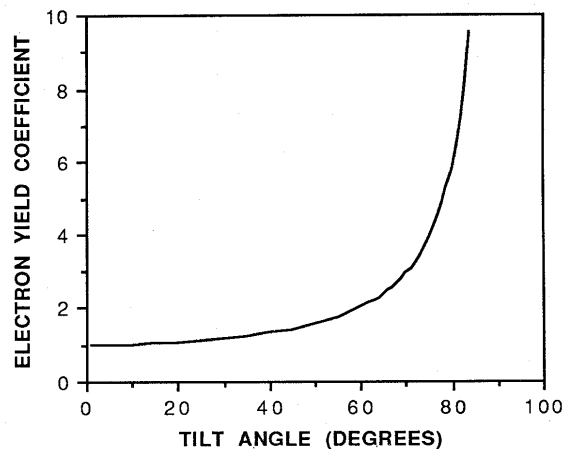


Figure 1. Inverse cosine function of electron yield vs. tilt angle.

A Hitachi S-2500 Scanning Electron Microscope was utilized for characterization of the Passive Voltage Contrast phenomenon. Figure 2 is a block diagram of the S-2500 system which includes the locations of SE detector 1 which is the through the lens detector as well as SE detector 2 which is the normal chamber detector.

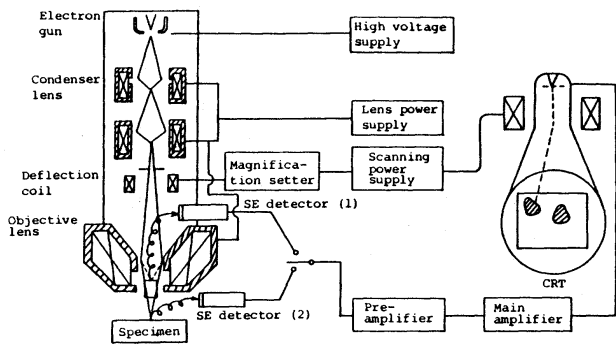


Figure 2. Block diagram of S-2500 SEM system.

A section of an EPROM wafer was selected for characterization of the Passive Voltage Contrast (PVC) technique. The wafer was first stripped of metallization in order to expose the polysilicon and diffusion contact windows. This deprocessing step prepares the wafer for PVC study. The wafer fragment was mounted to an aluminum specimen stub using conductive carbon paint and placed in the SEM. Zero tilt angle and SE detector 2 were selected initially for imaging. Changes in raster scan (magnification) of the primary beam at 1000 volts left no indication of localized surface charging. Additionally, no discernible contrast differences were noted between floating gate contacts and diffusion contacts. At low magnification the tilt angle of the device was then increased, and as expected, the secondary electron current and subsequently the brightness of the image increased. A 60° tilt angle was selected for characterization of the technique since the depth profile of the contact windows make higher tilt angles impractical. The magnification was increased to 1500X at which point the image brightness was observed to rapidly fade as the surface charged to a stable equipotential. Figure 3 is an SEM micrograph, taken at 50X, which illustrates the area affected by the primary beam scan. Remember, since the primary beam energy is low, the familiar effect of unstable charging is not applicable. The magnification was increased back to 1500X then the beam was set for a reduced raster scan and focused on one of the contact windows associated with the polysilicon control gates. Normal scan was resumed at 1500X and immediately photographed. Figure 4 illustrates the result of "programming" one floating control gate with a concentrated scan while imaging the rest of the gates in the field at a reduced scan. Note the "programmed" gate now has a dark contact window. Although all the gates imaged gather charge from the primary electron beam, the time to charge is dependent on the dwell time of the primary beam to inject charge into the contact window as well as other factors such as capacitance of the gate and beam current. Both SE detectors function with PVC, however, working distance with tilt angle is a limitation associated with SE detector 1.

Figure 3. SEM micrograph which illustrates the effect of surface charge from the primary electron beam. The dark squares are the result of concentrating the raster scan of the electron beam.

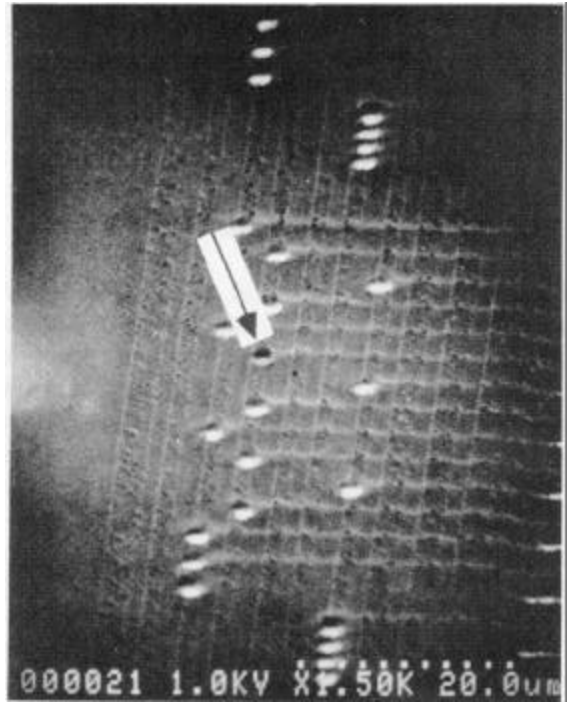
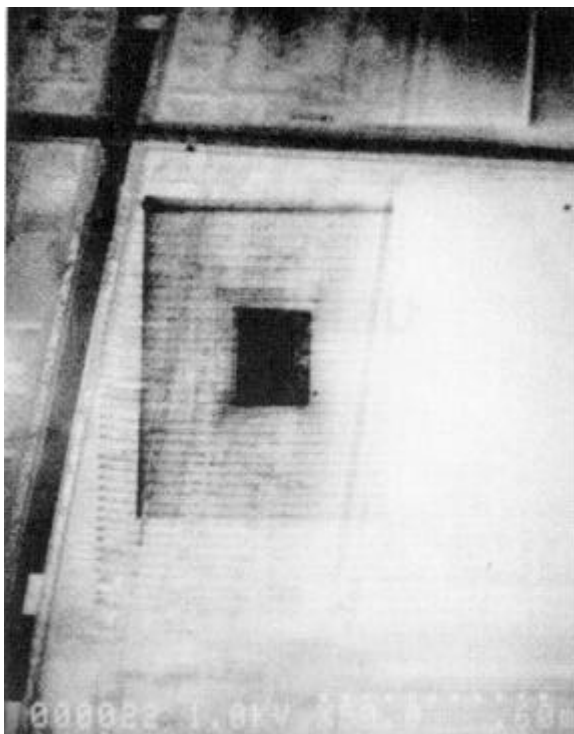


Figure 4. SEM micrograph of a series of uncharged floating control gates. A control gate in the center has been charged by concentrating the scan of the primary electron beam.

Failure Analysis Applications

A 3 μm device was submitted for failure analysis due to a low level input leakage failure. This part was characterized for leakage to Vss on the curve tracer and no obvious leakage was observed. The part was then characterized with a picoammeter on pin 3 while biased. 50 nA of leakage was measured compared to a typical value of 5 nA. Increasing the temperature resulted in an increase in leakage for pin 3, and a decrease in leakage for the remaining inputs.



The part was opened with fuming nitric acid and examined. No defects were observed. Passivation was removed and the leakage isolated to the first inverter of the input by severing the metal line mechanically. Metal was then removed and the part examined in the SEM utilizing Passive Voltage Contrast. Figure 5 is a PVC image which identifies the failing p-channel gate responsible for the leakage. Note the illuminated contact.

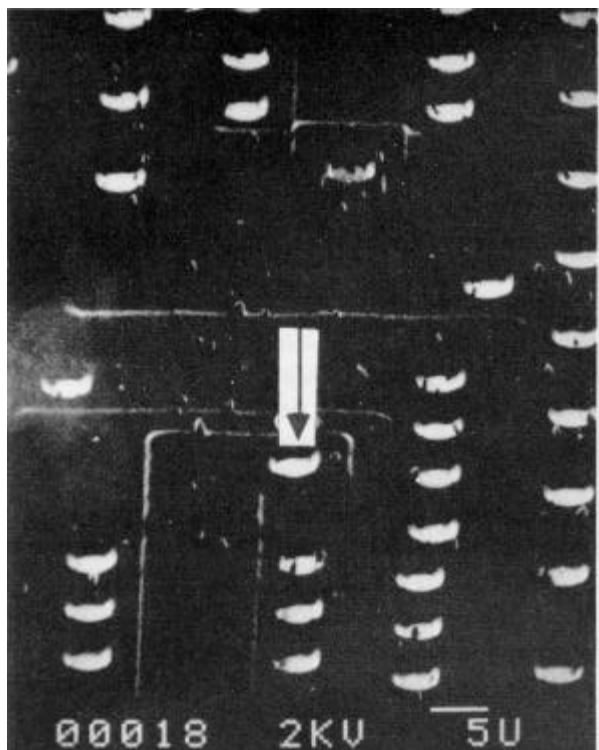


Figure 5. SEM micrograph of the defective p-channel transistor as identified by Passive Voltage Contrast (center). The n-channel device (above) is normal.

The gate leakage was confirmed on the curve tracer as a diode from gate to source and a diode from gate to drain. These characteristics implied that the leakage was in the gate channel. Removal of the poly revealed the gate oxide integrity defect in the channel. (Figure 6)

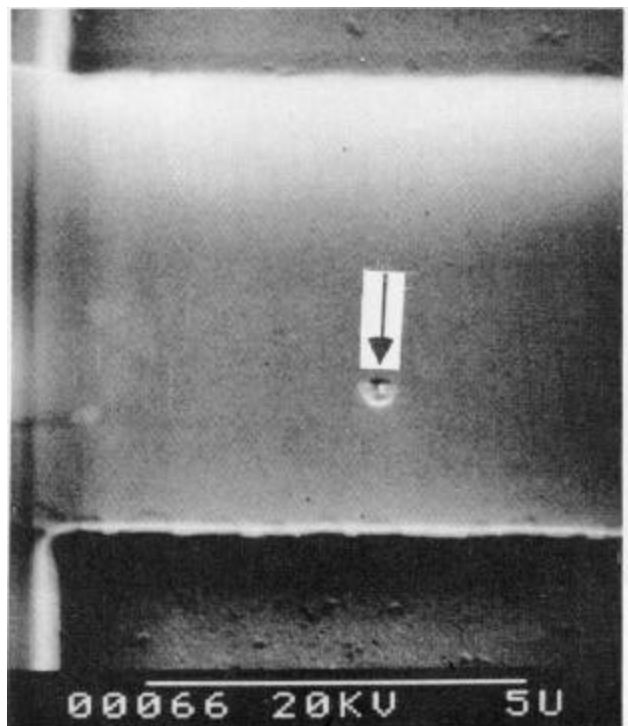


Figure 6. SEM micrograph of the oxide integrity defect responsible for the 50 nA of input leakage.

Initially, the concept of charged oxide appearing darker is not intuitive since the electron beam will charge non-conductors to a negative potential resulting in increased intensity. Note that the accelerating potential is kept low so that the surface oxides will charge minimally and achieve a stable equilibrium. In addition, tilt angle serves to increase the

secondary electron yield of the conducting surfaces while the non-conductors maintain an equilibrium potential.

Passive Voltage Contrast for Non-destructive FAB Process Analysis

A Cvikscan 3E SEM is being utilized as an in-line diagnostic tool for identifying Process Control Monitor (PCM) gate leakage after the gate mask step.

Background

A particular process monitor gate was found to be shorted at probe. Wafers were pulled after metal etch and were observed to already have the gate short. Where in the FAB process is this gate being destroyed?

This question needs to be answered without destruction of a considerable number of wafers since this is a low volume product.

Procedure

A wafer was pulled from the lot after contact mask and run in the Cvikscan at a 50° tilt. This angle was selected due to the depth of the contacts. Figure 7 is an SEM micrograph of the contacts associated with the defective gate as determined by PVC. Note the illuminated contacts since the gate cannot charge to an equilibrium value with the oxide.

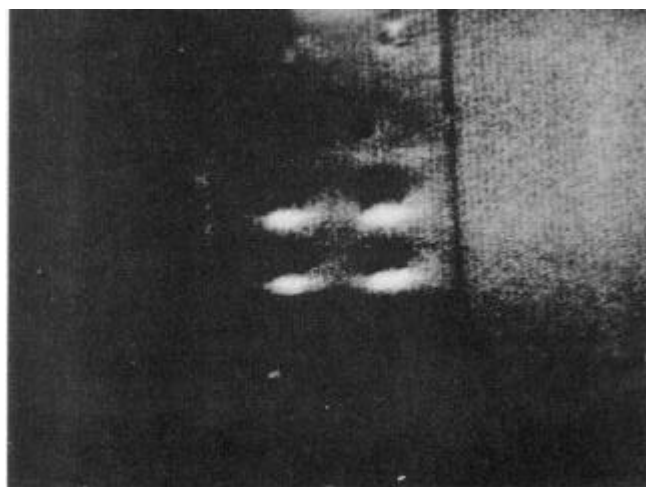


Figure 7. SEM micrograph of the illuminated contacts associated with a defective PCM gate.

Figure 8 is an SEM micrograph of the contacts associated with an adjacent normal gate as determined by PVC. Note the gate is charged to an equilibrium value with the oxide, thus the contacts appear dark. An additional wafer was pulled after gate mask. PVC was utilized and the gate short found to be present

in spite of the high poly resistance and lack of a source-drain implant at this level.

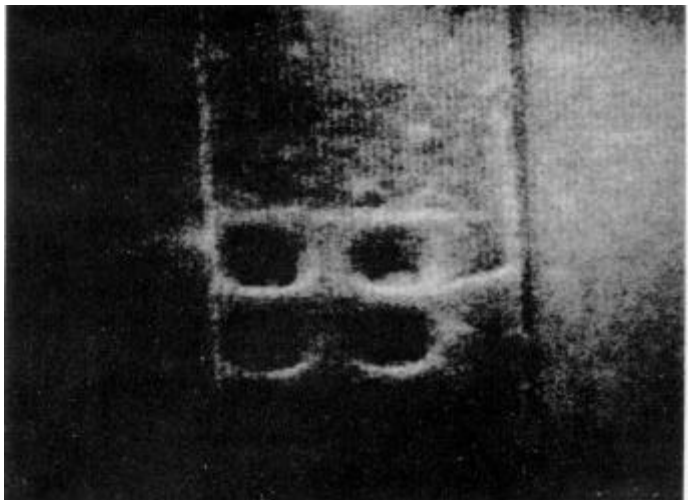


Figure 8. SEM micrograph of an adjacent normal PCM gate as determined by PVC.

Poly was removed and the gate oxide examined. Figure 9 illustrates the gate oxide defect responsible for the short. The process step responsible for the failure was identified using PVC and process changes were made to rectify the gate short.

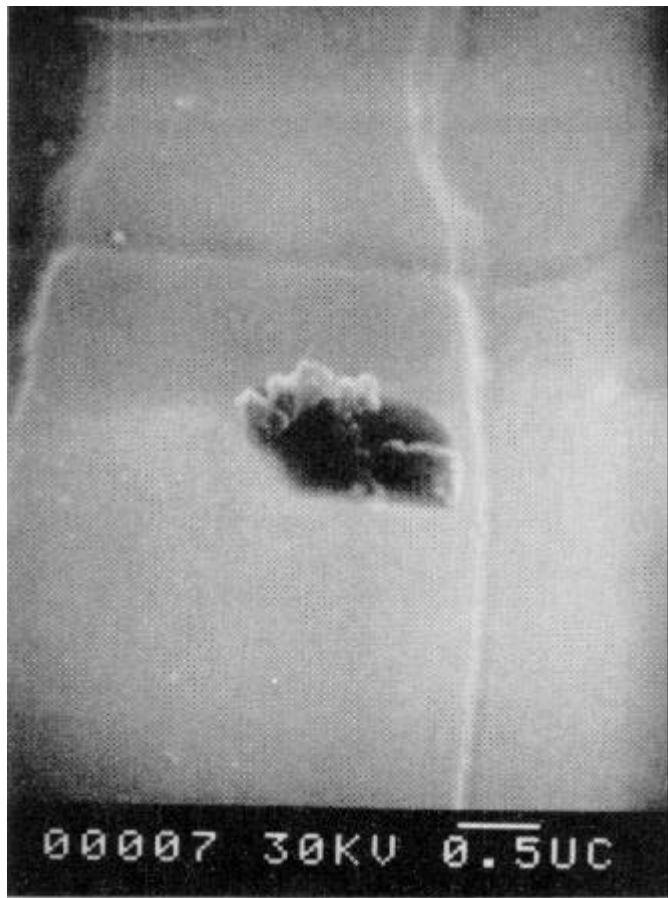


Figure 9. SEM micrograph of the gate oxide defect responsible for the short.

Thin film determination

Nonconductive thin film contamination over associated conductors can be characterized using Passive Voltage Contrast.

Background

Poor bond adhesion was observed associated with a particular die in a hybrid assembly. Examination of the foot of a lifted gold ball bond revealed minimal intermetallic formation.

Procedure

The part was placed in the SEM at a 55° tilt angle and imaged at 5 KV beam voltage. Figure 10 is a PVC image of the bond pad. Note the illuminated area on the pad associated with the probe mark from wafer sort. This illuminated area reveals the exposed aluminum and effectively maps the thin film on the bond pad.

Energy Dispersive X-ray analysis (EDX) was performed on the bond pad in order to confirm the PVC findings. Figure 11 is an EDX spectra of the probe mark area. Note the prominent aluminum peak. Figure 12 is an EDX spectra of the bond pad over the thin film. Note the aluminum and silicon peaks. The tilt angle was changed to 30° and an EDX spectra obtained over the thin film (Figure 13). Note the decrease of the silicon peak due to increased beam penetration through the thin film. Subsequent Auger analysis revealed a film composition of silicon and oxygen due to an incomplete etch at pad mask.

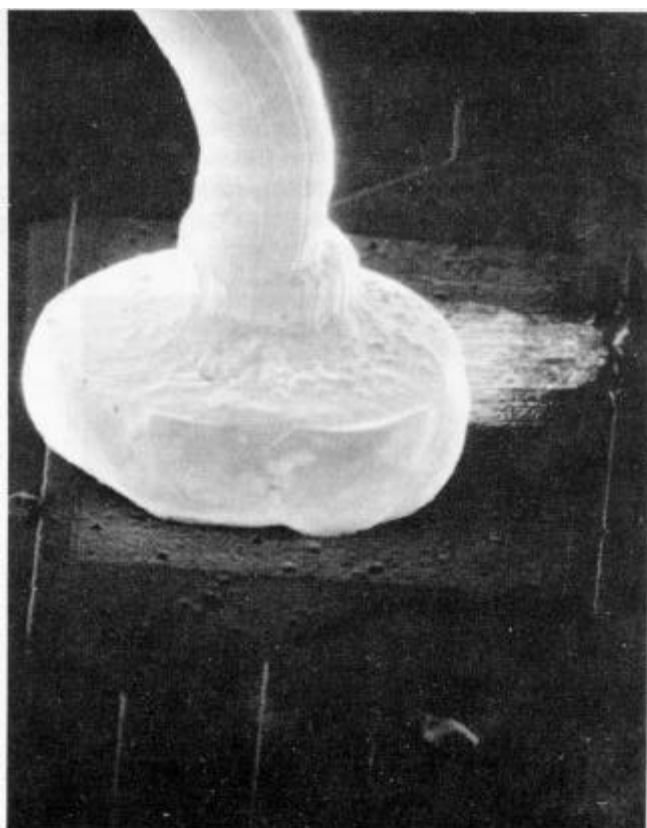


Figure 10. SEM micrograph of the thin film contamination. Note the location of exposed aluminum due to the probe mark.

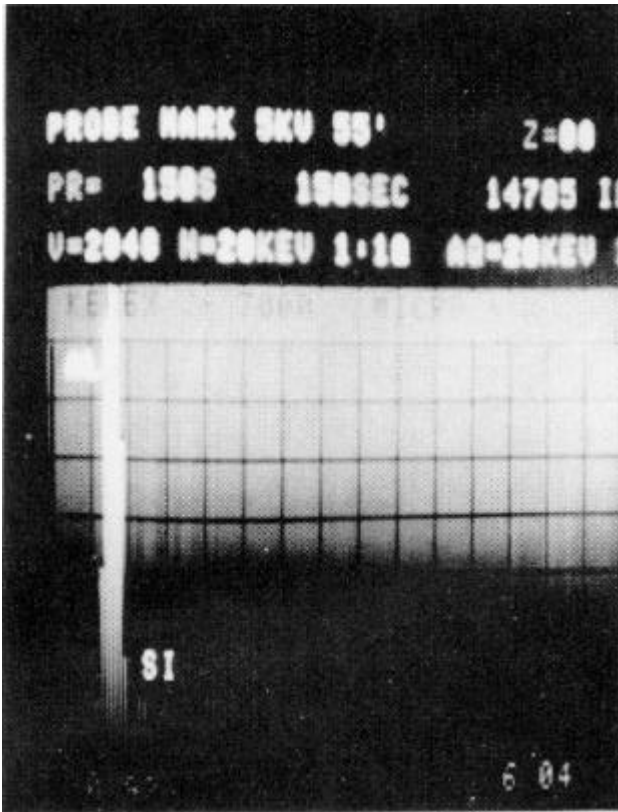


Figure 11. EDX spectra of the probe mark area on the bond pad.



Figure 12. EDX spectra of the thin film over the bond pad.



Figure 13. EDX spectra of the thin film associated with the bond pad at a 30⁰ tilt angle.

Conclusions

The results of the work presented in this paper lead to the following observations:

1. The beam current injected depends on spot size as well as the scan area (magnification). Typically the injected current is in the tens to hundreds of nanoamps. The injected beam current is typically lower than the reverse bias leakage of pn junctions. As a result, isolated wells will leak to substrate enabling the gate leakage to be readily identified.
2. Use of the electron beam to impinge a charge on the floating gates makes it possible to determine presence of leakages much lower than the nanoamps range with beam blanking techniques.
3. Relative capacitance values can be obtained by determining a time constant to charge for a given gate area, beam current, and magnification factor.
4. Presence of thin oxides can be readily distinguished on bond pads or other conductors.

All who have mechanically probed the contact windows of gates which are suspected of leakage are aware of the difficulty in determining whether the gate doesn't leak or if the probe isn't making contact. Frequently the contact window is damaged as a result.

Passive Voltage Contrast does not require external amplification or biasing as is the case with Electron Beam Induced Voltage (EBIV), Current (EBIC), and conventional voltage contrast schemes. Passive Voltage Contrast has been in active use since September of 1989 and has proven to be an important analysis tool by allowing the analyst to rapidly identify gate leakage without destructive and tedious mechanical probing.

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