PicoCurrent™ imaging using the Multiscan™ Atomic Force Probe

Application Note PC1-04

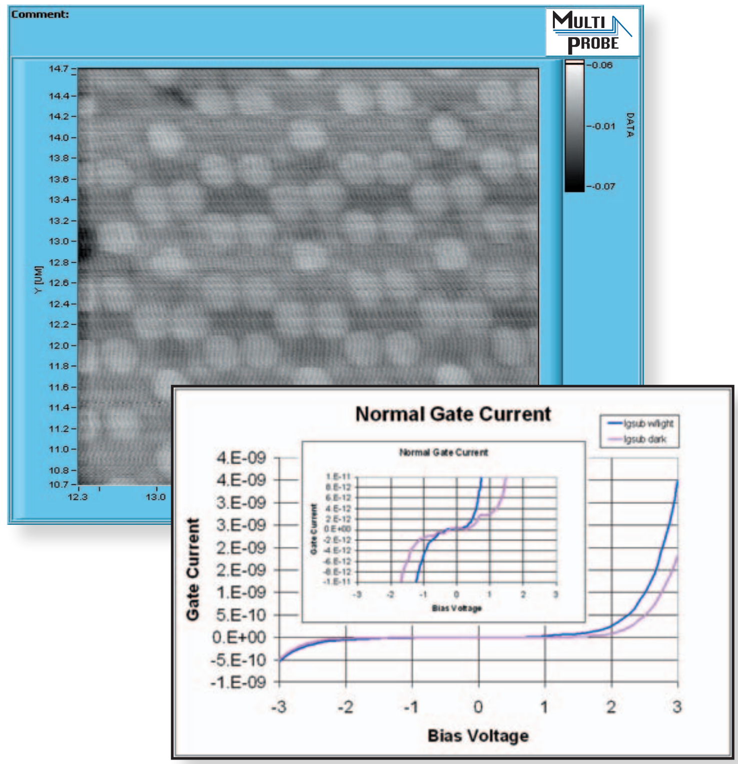

Figure 1: (top) Topographic image of contacts on the sample used in this analysis. Probes may be placed using this image and IV parametric curves extracted. Figure 2: (bottom) IV Curve taken by biasing the normal gate contact on the sample in Figure 1. The effect of light can be seen in the two curves. (Inset: Scale reduced to show low current at low bias values.)

PicoCurrent™ Imaging and the AFP

The Atomic Force Probe or AFP is a specialized Atomic Force Microscope or AFM. The AFP contains most elements of an AFM. However, it also provides advantages to traditional AFM such as the ability to use multiple probes in close proximity and tungsten wire needles for ohmic contact to metals used in semiconductor processing. The AFP provides a low leakage electrical connection to the probe tip and the tip may be biased and current recorded together with the standard topographical micrograph.

Current Contrast Mechanism vs. Passive Voltage Contrast

The AFP probe is connected to the input of a very high gain current amplifier. Either the probe or sample may be biased with respect to the other. When the probe is scanned in contact mode, it touches each feature in the image. Because the probe tip is solid tungsten, very low resistance ohmic contact is achieved and a current is measured and recorded. The current reflects the bias, contact resistance, and the underlying structure scanned. [1]

For instance with a probe biased negatively and substrate grounded, each contact to a p-type implant in an N-well, as would be typical for a CMOS process, will show a reverse biased diode current in the low pA. The current is limited by the presence of the second junction of N-well to P-substrate. The n-type source/drain implants will be a forward biased diode connection and pass currents in the 10 μA range for biases in the 1Volt range.

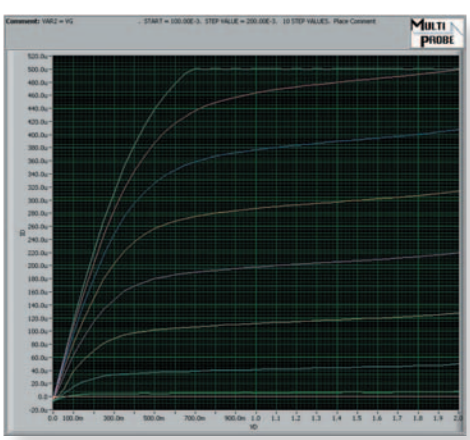

Figure 3: Transistor Family of Curves extracted from a typical Nfet of the process above.

If the probe is biased positively relative to the substrate the resulting current map will reflect a slightly more complex case. When the positive probe contacts an n-type implant, it sees a reverse biased diode to the substrate via Pwell and will pass about a nA of current much higher than in the negative, reverse bias case. The forward bias diode case to the p-type S/D implants is complicated by the presence of the N-well and will conduct through a parasitic pnp light activated bipolar transistor formed with the contact as the emitter, the well as the base and the substrate as the collector.

The gates will ordinarily conduct a few pA to a nA depending upon the gate oxide technology. The current sample will pass a few hundred pA for a bias of 1V with the conduction a little stronger on the positive bias. The asymmetric tunneling current in a CMOS system will stem from the more favorable electron tunneling from the n+ source into the Nfet gate. Figure 2 shows a typical tunneling or

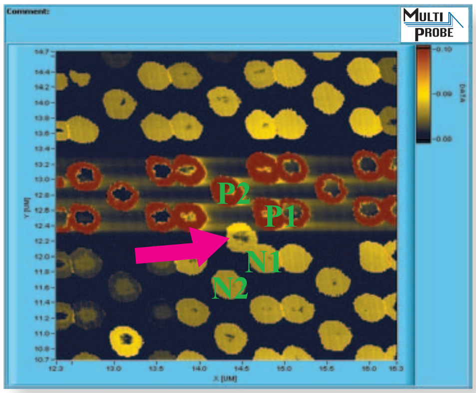

Figure 4: PicoCurrent™ image showing a damaged gate. Bias 80mV Gain 100M.

leakage current IV curve taken biasing an inverter gate relative to the P type substrate. The floating P contacts will be affected by light incident on the sample as can be seen in the figure. The probe is connected to an HP 4145B Parameter Analyzer for the IV sweeps.

Gate Oxide Damage and Current Mapping

Figure 4 shows a PicoCurrent™ image obtained in the same scan as the topographic image of figure 1. The current map gives not only better signal to noise data than the topographic map, the contrast in current flow gives an instant look at the layout in the sample. The Nfet contacts are shown in yellow and the Pfet contacts in brown. The contact map even shows the cleavage line natural in the damascene deposition process. A leaky gate is shown by the pink arrow in the figure and the IV curves in figure 5 reference the contacts around this leaky gate.

Figure 5 shows the Gate to Source/Drain leakage as measured with two probes. The leakage current on the damaged gate is significantly higher than a normal gate on each of the four curves, however the curve on N2 shows the predominant current flow. The flattened aspect from the Ps/d leakage is from the light induced

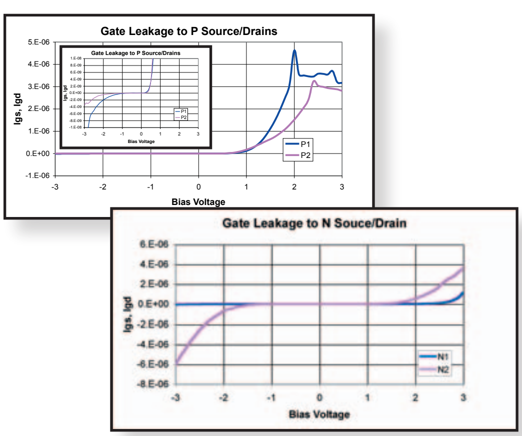

Figure 5: Gate Leakage Current measured with two probes around leaky gate shown in figure 4. N2 is shown to be the main site of damage.

effect. The current on all contacts is orders of magnitude higher. It would be expected that the IV characteristics of such a transistor would be adversely affected. However until the introduction of the AFP, it would have been nearly impossible to carry out such a study.

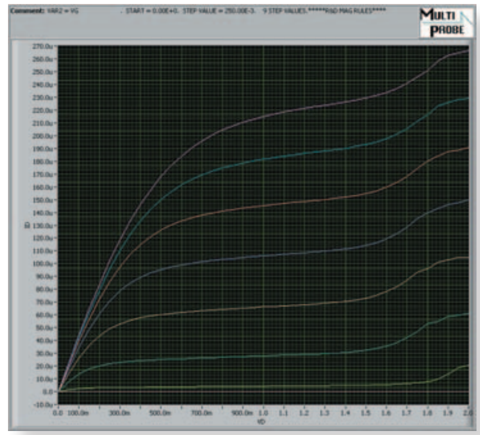

Figure 6: Ids vs. Vds curves from the leaky gate Nfet....

Transistor Parametric Characterization

The AFP distinguishes itself from conventional AFM through the ability to use multiple probes in very close proximity to contact all terminals of the device. Figure 6 shows the Ids vs. Vds family of curves from the illuminated (leaky) gate contact shown in figure 4. The leaky curve was extracted at Vdd=2V. The leaky gate appears to affect the channel transconductance at higher drain voltage regardless of gate voltage.

The Pfet curves from the same device did not show the same effect. The gate damage took place on the Nfet S/D as the most likely location of high tunnel current.

Conclusions

The highly sensitive fault localization technique of current imaging combined with the parametric extraction ability of the AFP form a powerful analytical tool. Extension of the single probe AFM technique to a multiple probe AFP allows the user to perform all necessary measurements to characterize either a failure or to evaluate a process at the contact node level. Imaging requires a few minutes and IV curve extraction a few minutes more.

References

[1] Jon C Lee, J H Chuang "Fault Localization in Contact Level by Using Conductive Atomic Force Microscopy" Proceedings from the 29th International Symposium for Testing and Failure Analysis, 2003, pp 413-418.

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