Proceedings of the 32nd International Symposium for Testing and Failure Analysis
November 12-16, 2006, Renaissance Austin Hotel, Austin, Texas, USA

Conductive Atomic Force Microscopy Application for Semiconductor Failure Analysis in Advanced Nanometer Process

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Abstract

Conductive Atomic Force Microscopy (C-AFM) is a useful tool for both electrical failure analysis (EFA) and physical failure analysis (PFA). In this paper, the root cause of a physical failure in an analysis image was verified from the evidence of two-dimensional AFM profile depth measurement. The other analysis technique, which is electrical parameter extraction by contacting I-V spectroscopy measurement, was also utilized to locate the possible defects. As a result, the failure mechanism was illustrated with an AFM topography image, which showed the silicon surface profile after removal of cobalt salicide (self-alignment silicide) by dilute HF. The vertical junction leakage path was identified with a C-AFM image.

Introduction

Scaling of semiconductor technology is more complicated at nanometer dimensions. This impacts conventional failure analysis technology. SEM/FIB passive voltage contrast (PVC) is commonly used for detecting different potentials for failure mode analysis, e.g.: opens, shorts, and leakage. However, as the process progresses into the nano scale, manufacturing parameters are trending toward extreme values. As the transistor is fabricated with extra-shallow junctions and poly gate oxide thickness of less than twenty angstroms, the extremely small size of the contact circumference is insufficiently charged by electrons or ions, so that PVC is less sensitive to some of the failure modes, such as leakage, or higher resistance.

Conductive Atomic Force Microscopy (C-AFM), which is more accurate and sensitive than PVC, provides a large dynamic current detecting range from 1pA to 10mA for wide-scale semiconductor failure analysis. The current mapping image combines topography with electrical parameter characterization, which makes it easier to compare between good and bad contrast, as in PVC methodology. In this article, another analysis technique, electrical parameter extraction by contacting I-V spectroscopy measurement, is also utilized to verify the possible defects.

Experiment:

Electrical failure analysis (EFA) was performed using several precision analytical techniques for defect localization, e.g. MCT (Mercury Cadmium Tellurium) detector, IR-OBIRCH (Infra-Red Optical Beam Induced Resistance Change) and PEM (Photo Emission Microscopy). Physical failure analysis (PFA) was performed for failure mechanism discussion, using tools and techniques such as FIB (Focused Ion Beam), PVC (Passive Voltage Contrast), TEM (Transmission Electron Microscopy), and C-AFM (Conductive Atomic Force Microscopy).

Case Study: Nano-scale extra-shallow junctions affected with silicide-roughness-induced leakage issue

Failure Analysis Procedure:
In this case study, a leakage current of 77uA at 0V was measured on the failing sample. This leakage current was compared with that of a good sample, which has leakage current lower than 6.8uA (Fig. 1.). Both the low-static state (0V) and the I-V characteristic curves of the failing pin were different from those measured from the reference sample.

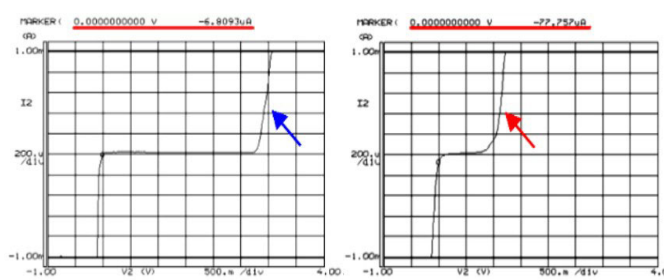

Figure 1.a: The (good) reference sample I/V curve showed the 6.8uA current at "Low state (0V)".
Figure 1.b: The I-V curve also show early turn "ON state", and "Low state leakage of 77uA@0V".

A backside MCT photoemission detector technique was performed, which attempted to localize the defect precisely. After zooming in to 1000x, a strong and solid MCT signal spot was found at an electrostatic discharge (ESD) device, as shown in Fig. 2.

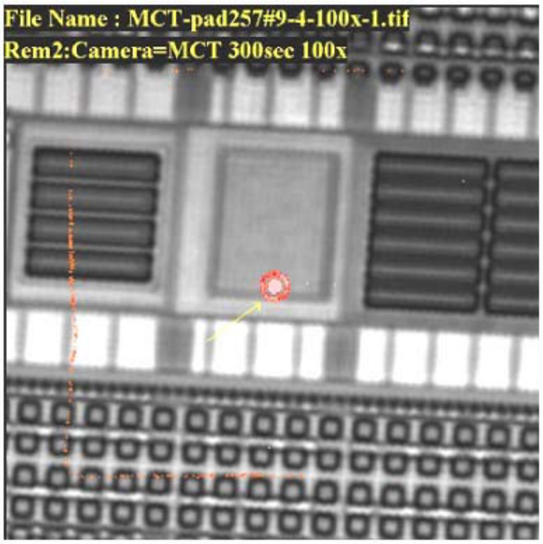

Figure 2: 1000x Zoom, a precise Backside MCT spot was detected at the ESD protection device.

Passive voltage contrast (PVC) technique is used for detecting different potentials. However, in this advanced nanometer process sample, the extremely small contact size is insufficiently charged, so that PVC is ineffective because of its low sensitivity, as shown in Fig. 3.

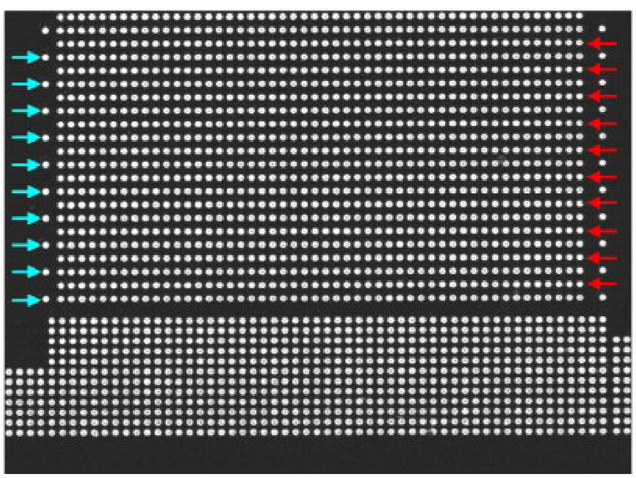

Figure 3: Both n^+ diffusion contacts of odd rows (indicated by blue arrows) and p^+ contacts of even rows (indicated by red arrows) could not be distinguished by contrast difference using FIB PVC.

C-AFM, which application is extended in the nanometer-scale failure analysis, is introduced in this paper. C-AFM acquires both topographical and electrical information by a contacting signal feedback between an AFM probe tip and the sample surface (Fig. 4).

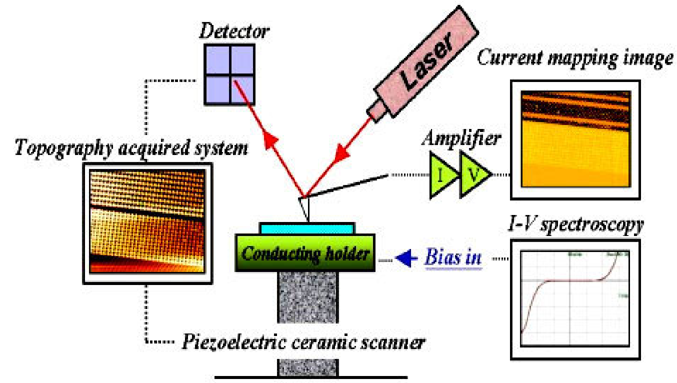

Figure 4: C-AFM operation illustration.

The suspected MCT spot was widely scanned for more accurate defect localization using C-AFM. There are three images generated simultaneously while scanning the sample surface using the C-AFM (Fig.4) . The top-left image is the AFM topography. The bottom-left image is the current mapping information and the bottom right image is the I/V spectroscopic curve taken at a point on the sample. On Fig. 5, a green cross in a blue circle indicates where the I-V spectroscopic measurement was performed on the sample, It shows the normal n^+ diffusion junction as a bright white-yellow colored contact (Fig. 5). Based on the abnormal dark black contact, a leakage issue was detected and was confirmed by I-V curve spectroscopy (Fig. 6). The curve is like that of a junction leakage issue, as shown in Fig. 6.

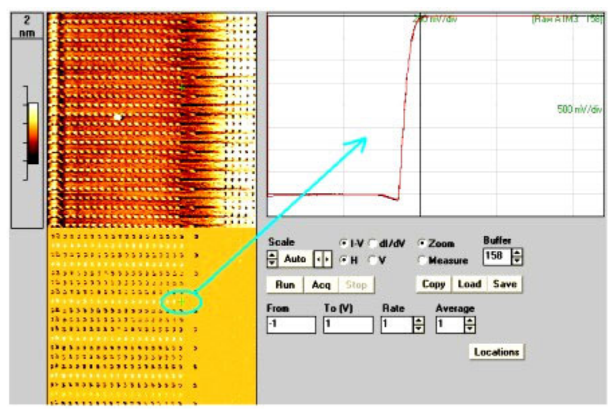

Figure 5: A good I-V spectroscopy measurement measured from a normal n^+ diffusion junction shown as bright white on the C_AFM current map..

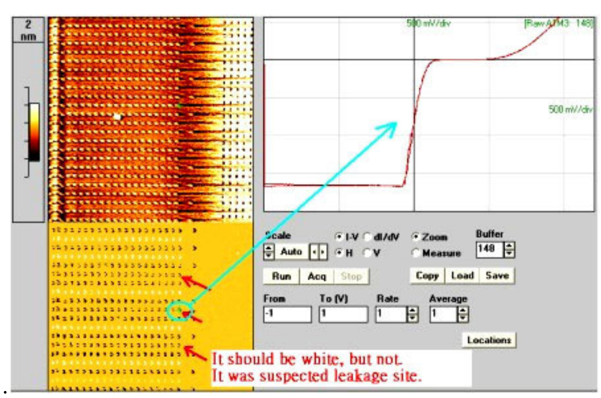

Figure 6: Three abnormal dark black contact rows were detected as leakage sites, which was confirmed by I-V curve spectroscopic measurement.

Physical Failure Analysis Procedure:

Based on the C-AFM current map information, a step-by-step X-SEM FIB technique is used to search for the suspected n+ diffusion contact rows. An obviously abnormal deeper silicide spike was found (Fig. 7) on the failing area. For advanced inspection, TEM was performed and the silicide spike depth of 65.4nm (Fig. 8) was measured, which is twice as deep as average silcide roughness.

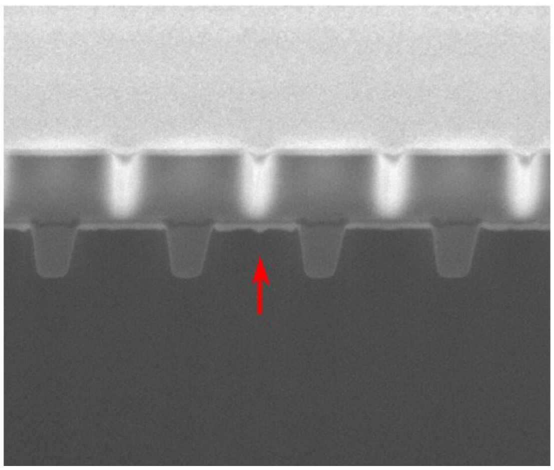

Figure 7: A silicide spiking at the suspected n+ diffusion contact row was located by step-by-step FIB x-sectioning..

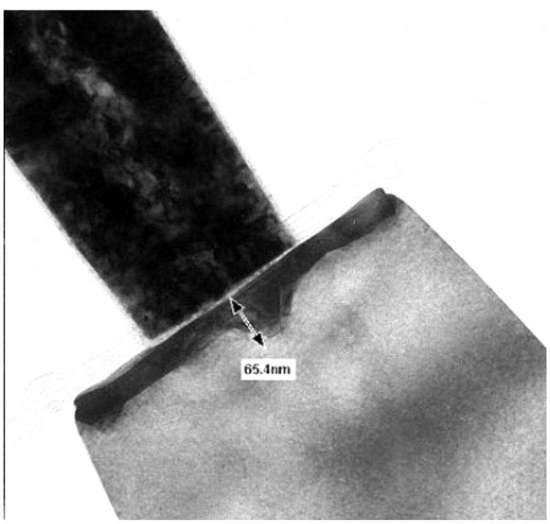

Figure 8: The abnormal silicide spike was measured as 65.4nm.

On the failing sample, after removing the cobalt salicide using dilute HF, the surface roughness distribution and geometry were measured using AFM. It was determined that the surfaces of the p+ diffusion rows were smoother than the n+ diffusion rows and that they had fewer dark black cavities. The p+ vertical profile measurement was about 1.5nm, and the n+ diffusion vertical measurement was about 40nm, as shown in Fig. 9.

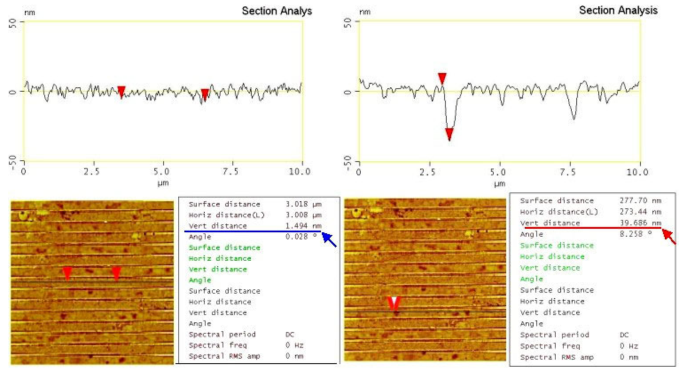

Figure 9: AFM Topographical Images: the left shows the p+ diffusion surface afm image with vertical profile measurement of 1.494nm and the right afm image shows the dark black surface cavities of the failing n+ diffusion. This had a vertical path of 39.686nm

Result and discussion:

Fig. 9 shows the AFM topographical image of the failing n+ diffusion with several deep surface cavities. After the silicide process, the cavities were formed like a leakage valley. There is a high-risk leakage source for an extra-shallow junction transistor. As the process progresses into the nano scale, the material selectivity for extra shallow junctions needs to be tightly controlled.

Summary and Conclusion

Our research provides significant evidence that C-AFM inspection is highly suitable for both electrical failure analysis and physical failure analysis. In the case study, the root cause of a electrical (leakage) failure was verified using the two-dimensional AFM depth profile measurement. The failure mechanism was then illustrated with an AFM topography image. Based on the C-AFM results, the extra-shallow junction leakage issue has been identified and resolved. As a result, we have been able to subsequently improve yields of these processes.

Acknowledgments

The authors would like to thank Dr. W. T. Chang for kind advice and support.

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