

# Focused Ion Beam Method for Reconditioning Worn Tungsten Atomic Force Probe Tips

Randal Mulder, Sam Subramanian, Tony Chrastecky

Freescale Semiconductor, Inc; 6501 William Cannon Drive, Austin, TX 78735

## Introduction

Atomic Force Probing (AFP) uses very sharp tungsten tips (100nm in radius) to map the surface topology of a semiconductor devices that have been deprocessed to a layer of interest most often to the top of the tungsten plugs (contacts) [1,2,3]. The information gained from scanning and mapping the surface topology is used to construct an image of the surface (Figure 1). Once the locations of the plugs have been established, the tungsten probe tips that were used to probe the contacts connected to the underlying transistors [4].

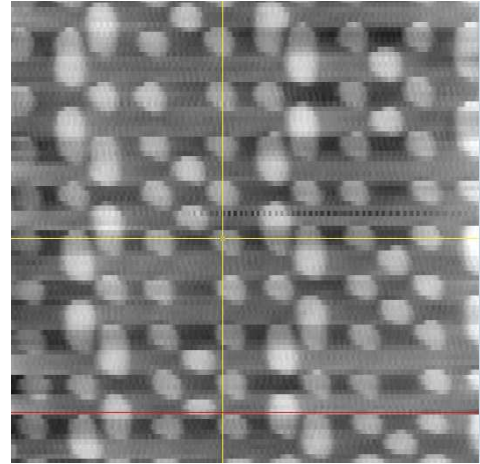
Tungsten probe tips do not produce images with the same quality as silicon tips used for traditional Atomic Force Microscopes (AFM) due to the larger tip size, but tungsten is much more durable and a better electrical conductor for probing. The image quality produced by tungsten probe tips is usually sufficient to allow probing of 90nm CMOS technology.

Even with the greater durability of tungsten, the tips wear out rather quickly. Each tip scans a small area of the device in the contact mode. A piezo electric feed back loop is used to keep a constant force on the tips against the surface of the device. As the tips drag along the surface, they wear and become larger in diameter. New tips that provide adequate imaging of 90nm CMOS contacts wear out to the point where probing is no longer possible after just a couple of hours of use (Figure 2).

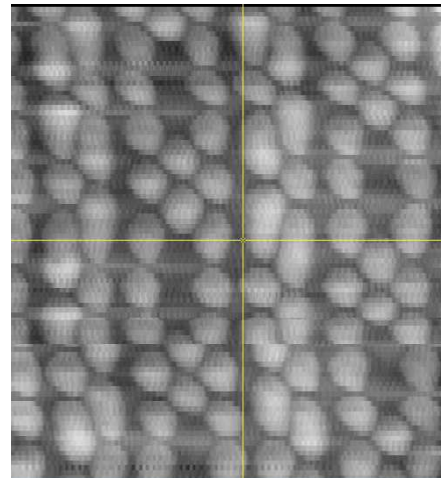
The purpose of this paper is to demonstrate how worn tips that no longer image and probe properly can be reconditioned using the Focus Ion Beam (FIB) tool. Tungsten tips as large as ~750nm can be sharpened down to 100nm and reused for AFP imaging. This method for reconditioning tips is straightforward and requires a minimal amount of time. Typically, four probe tips can be reconditioned in about 30 minutes on the FIB.

## Method

A focused ion beam (FIB) method was developed to recondition worn and slightly damaged tips for re-use. Also,



**Figure 1:** Image of 90nm CMOS tungsten plugs using an Atomic Force Probe (AFP) tool with new tungsten tips. Individual plugs are distinct and identifiable.



**Figure 2:** Image of 90nm CMOS tungsten plugs using the AFP tool with worn tips. Contacts appear larger and smeared together. Image quality has degraded and electrical probing is very difficult.

new tips on occasion, may not image or conduct current very well due to particulate or oxidation build-up if the tips haven't been stored or handled properly. This FIB method can be used to clean off the new tips and restore proper imaging and electrical conductivity.

Figure 3 shows an AFP probe tip assembly mounted on a Dual Beam FEI820 Focused Ion Beam (FIB) multiple-stub sample holder. The AFP tip assembly consists of a small printed circuit (PC) board with three connectors on one side, and a metal cantilever and a tungsten probe tip mounted at the end of the cantilever on the other side. The sample is mounted on its back with tungsten tip up. To save time, several tip assemblies can be mounted on the multi-stub holder for sharpening. Four tips can be sharpened in about thirty minutes

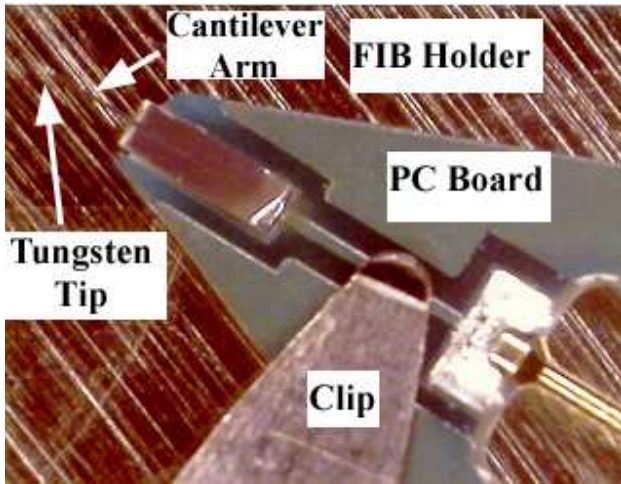


Figure 3: An AFP tip assembly mounted on the FEI820 multi-stub holder.

After the tip assembly is mounted on the holder, the holder is loaded into the FIB. The location of the tip assembly is found and imaged with the electron beam (Figure 4). The cantilever arm and tip are aligned vertically or 90 degrees perpendicular to the x-axis (Figure 5). Next, the tip of the tungsten probe needle is imaged at a moderate magnification level to perform eucentric positioning of the e-beam and ion beam. Eucentric positioning accomplished by the lowering/raising of the stage so that the tip of the probe needle meets the intersection of the of the ion and electron beams. This allows the image of the needle tip to stay centered in both the ion beam and the electron beam image even when the FIB stage is tilted (Figure 6).

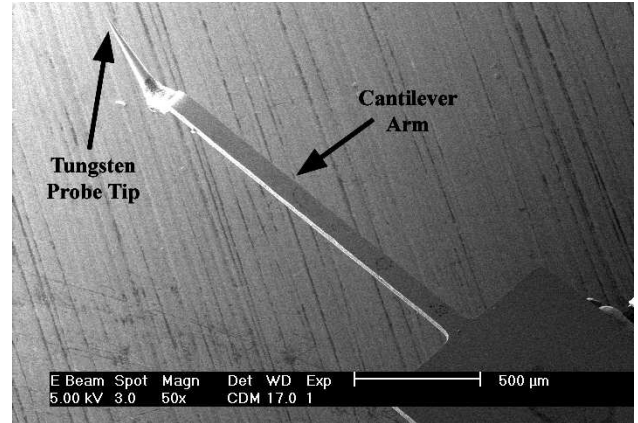


Figure 4: Electron beam image of the tungsten probe tip mounted onto the cantilever arm.

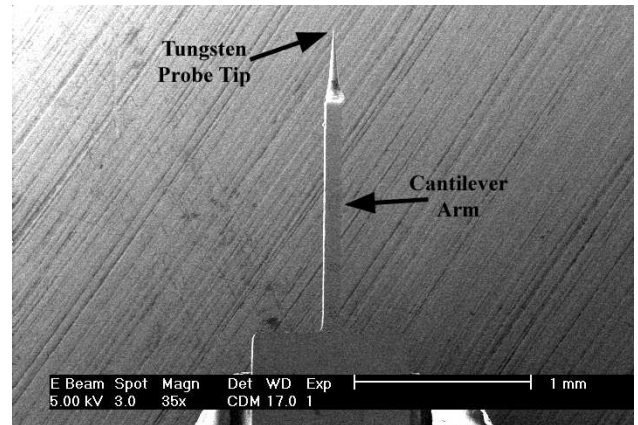


Figure 5: Electron beam image of the tungsten probe tip after the FIB stage was rotated (x-y axis) to align the probe tip vertically in the screen.

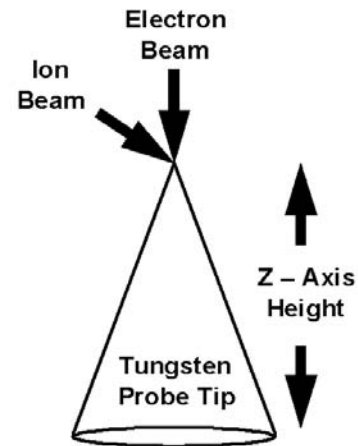
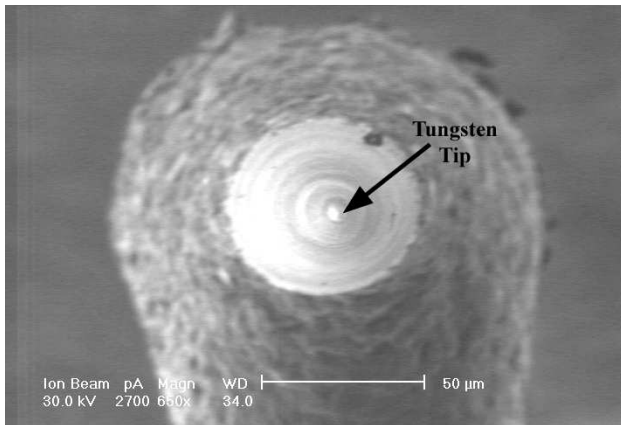


Figure 6: Diagram of the eucentric positioning. The FIB stage is raised/lowered to a height where the tip of the probe needle meets the intersection of the ion and electron beam.

After eucentric positioning is performed, the tip of the tungsten needle is imaged with the ion beam. The FIB stage is usually tilted 18 – 24 degrees so that the ion beam images straight down onto the tungsten tip (Figure 7). The tip is then centered in the middle of both the ion beam and electron beam images.

After the tip has been centered, the tip is imaged with the ion beam. The beam current is set to a moderately low current level (on this tool it's set to 150pA); and the magnification is increased while live imaging on the tip until it appears large in the screen (Figure 8). Live imaging of the tungsten tip at high magnification with the ion beam will mill the tungsten reducing the tip diameter.

After a few seconds of imaging/milling, the ion beam is turned off and the tip is viewed with the electron beam. On the FEI820 tool, the tip diameter can be directly measured with the ruler function. If additional milling is required to reduce the diameter of the probe tip, the tip is re-imaged with the ion beam for a few more seconds. This procedure is repeated until the desired tip diameter is reached. The best imaging of 90nm CMOS contacts with the AFP occurs with a tip diameter of 100-150nm.

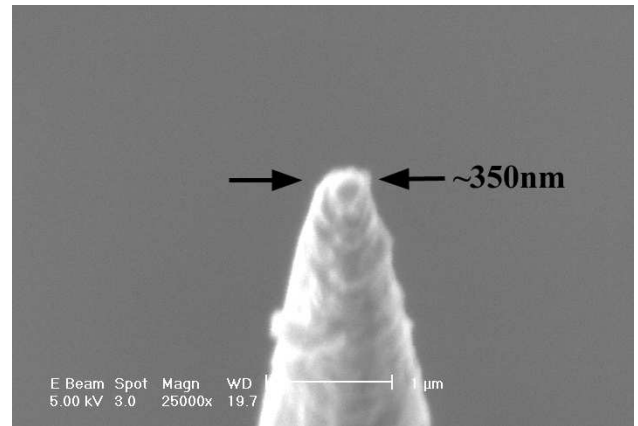


**Figure 7:** Ion beam image of the tungsten probe tip after the FIB stage was tilted 22 degrees. The ion beam is imaging straight down on the probe tip.

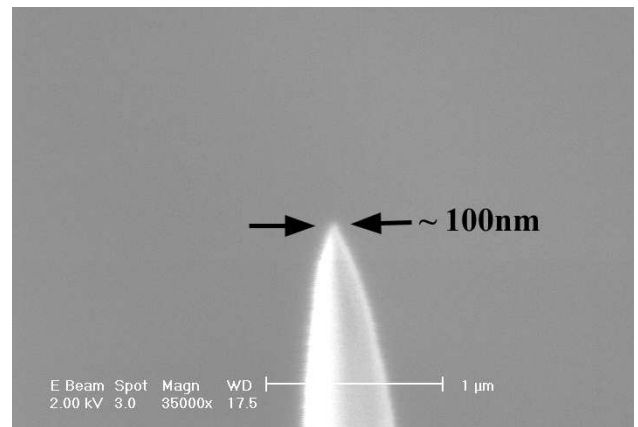
## Results

Figures 8 - 12 show examples of tungsten probe tips that were significantly larger than 100-150nm due to wear or damage. The tips were reworked with the FIB back to the desired diameter of 100-150nm. This method works best for tips that are under ~750nm in diameter and are not bent. Tips that are larger than this require excessive FIB milling and are very difficult to keep rounded. The grain boundaries within the tungsten tend to mill faster when excessive milling is

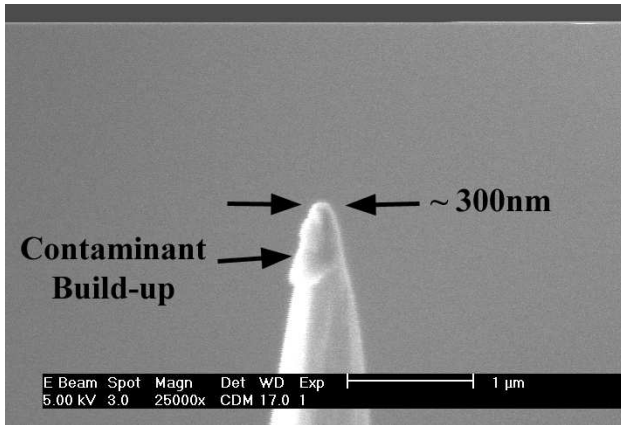
performed and a round conical tip shape is impossible to maintain. Reconditioned tips that are not conical produce poor AFP images. Therefore, it is recommended that tips that are too large or bent (the bent portion of the tip has to be cut off with the FIB and the remaining tungsten is too large to rework) be replaced. However, properly worn tips that are reconditioned produce images that are equivalent to new 100nm tips (Figure 14) and have similarly low resistance values for probing. The contact resistance values for new tips average ~100 ohms. Reconditioned tips have similarly low resistance values in the low 100 ohm range.



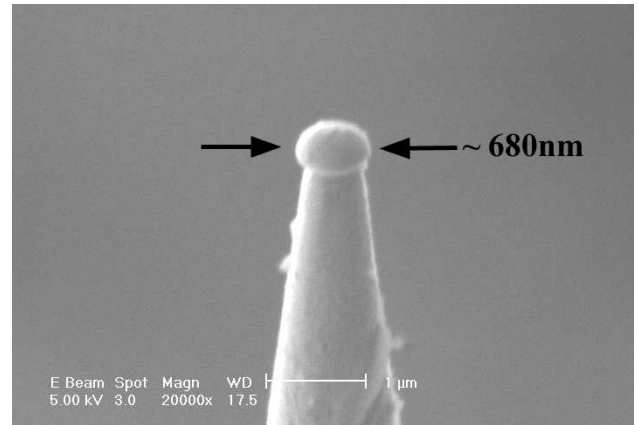
**Figure 8:** SEM picture of a used and worn tungsten AFP tip measuring ~350nm. The tip wore down after repeated scanning of the surface of the semiconductor device.



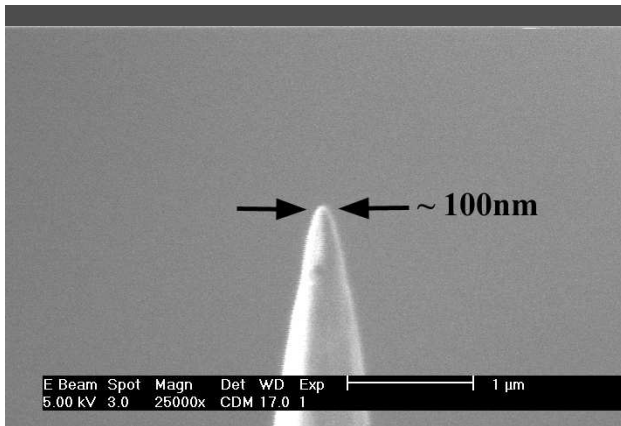
**Figure 9:** SEM picture of the same tungsten AFP tip shown in Figure 8 after reconditioning using the FIB. Tip diameter now measures ~100nm.



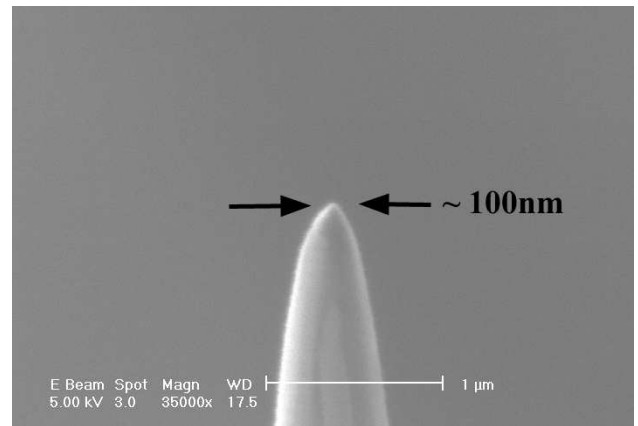
**Figure 10:** SEM picture of a used tungsten AFP tip measuring ~300nm. The tip wore down after repeated scanning of the surface of semiconductor device. Also, contaminants have built up on the tip reducing the electrical conductivity of the tips.



**Figure 12:** SEM picture of a used tungsten AFP tip measuring ~680nm. The tip was damaged when the transistor it was probing broke down due to an electrostatic discharge event that melted the tip.



**Figure 11:** SEM picture of the same tungsten AFP tip shown in Figure 10 after using the FIB. Tip diameter now measures ~100nm and the contaminants have been removed.



**Figure 13:** SEM picture of the same tungsten AFP tip shown in Figure 12 after reconditioning using the FIB. Tip diameter now measures ~100nm.

## Conclusions

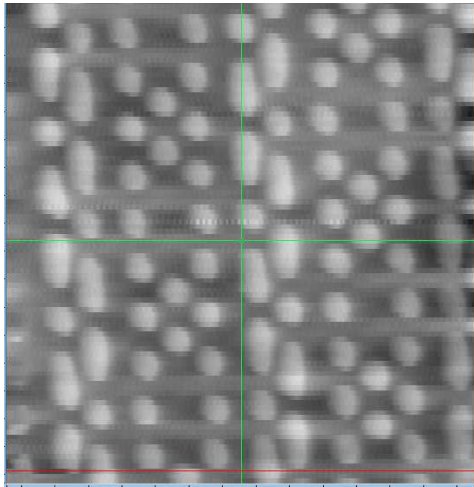
This paper presents a FIB method for reconditioning worn or slightly damaged tungsten AFP probe tips that no longer image or conduct properly. Reconditioned tips have imaging and conductivity performance similar to newly manufactured tips. This holds true for tips that have been reconditioned one, two, or three times at most. After two or three time, the tips will lose their conical shape and not image or conduct properly. It should also be noted that tips that are sharpened <100nm wear out or bend much faster than new tips.

This method works well for newly manufactured tips that don't work properly due to mishandling or improper storage

which allowed particulates/oxide to build up on the tip. These tips can easily be reconditioned and used to generate excellent AFP images. This method also works well for new tips that have been worn down (or slightly bent) after several hours of scanning and probing. Reconditioning of new or used tips requires exposure to the ion beam for only a few seconds to a few minutes depending on the amount of wear or debris on the tip.

Reconditioning of tips that are severely damaged or bent should not be attempted. The excessive amount of FIB work required would not be justified and the end results would more than likely not be satisfactory since the tips would not

retain their conical shape preventing proper imaging and probing.



**Figure 14:** Image of 90nm CMOS tungsten plugs using an Atomic Force Probe (AFP) tool with tungsten tips reconditioned with the FIB. Individual plugs are distinct and identifiable similar to the image produced by the new tip in Figure 1.

## References

- [1] Jon C. Lee, J.H. Chuang, “*Fault Localization in Contact Level by Using Conductive Atomic Force Microscopy,*” ISTFA Proceedings (2003).
- [2] Kenneth Krieg, Richard Qi, Douglas Thomson, Greg Bridges, “*Electrical Probing and Surface Imaging of Deep Sub-micron Integrated Circuits,*” *Microelectronic Failure Analysis*, ISTFA Proceedings (1999).
- [3] Kenneth Krieg, Douglas Thomson, Greg Bridges, “*Multiple Probe Deep Sub-micron Electrical Measurements Using Leading Edge Micro-machined Scanning Probes,*” ISTFA Proceedings (2001).
- [4] Andrew N. Erickson, “*What Can A Failure Analysts Do With An AFM,*” ISTFA Proceedings (2002).