Nanoprobing 14 nm transistors using the SMARPROBE

INTRODUCTION

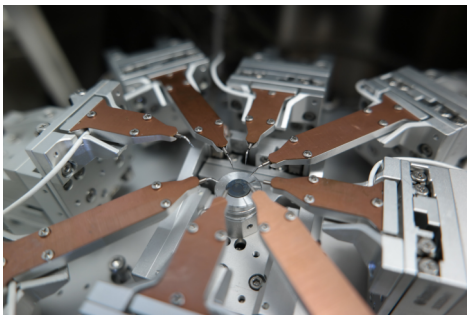
Due to the ever shrinking size and increasing complexity of modern integrated circuits the requirements for failure analysis become more and more ambitious. Addressing this issue, the SAM3 project, an innovation project of leading european chip and equipment manufacturers, was started in 2016 to accelerate the development of failure analysis tools capable of handling the demands of current and future technologies. Within this project SmarAct GmbH expanded the existing **SMAR**PROBE with the aim to become the stable, reliable and precise nanoprober for all future technologies to come. The result is the **SMAR**PROBE *LX*, a versatile closed-loop positioning system with an active temperature control and an extended scan range. The system can be easily inserted and removed into a high-resolution scanning electron microscope (SEM) due to the unique zero-force connector. The **SMAR**PROBE is designed to allow very short working distances within the SEM to improve the imaging quality at low acceleration voltages. To probe 14 nm transistor nodes or smaller it is therefore recommended to select an SEM with sufficiently good imaging quality at low acceleration voltages and low electron current densities to allow imaging of such sensitive materials.

PROBING

Preparation prior to the probing. The start of the work flow is the preparation of tungsten tips capable of contacting the nanometer sized transistor pads. You can either buy commercially available standard tips or produce you own tips with the **SMAR**PROBE *etch* (see Fig.Figure 1). The production step takes less than 10 minutes for the etching and the solution-based cleaning of three tips. By choosing one of the predefined etching recipes you can either produce robust tips which last many probing sessions or you can produce more flexible tips which are less aggressive to the sample surface. In any case the **SMAR**PROBE *LX* is designed to make the tips last as long as possible with the help of the unique *safe-approach* joystick controlled landing, the large scan range and due to the active position holding to avoid piezo creep as it occurs in open-loop probing systems. Long lasting tips combined with the fact that you can load several samples (up to four SEM stubs) reduces the amount of necessary venting cycles of the electron microscope and with it the down time of the system. To reduce the in-air time in between probing sessions the system has an automatic positioning for easy needle and sample exchange and subsequent referencing to a repeatable starting condition.

(a) Tip Preparation

(b) Tip Mounting



(c) Sample Mounting

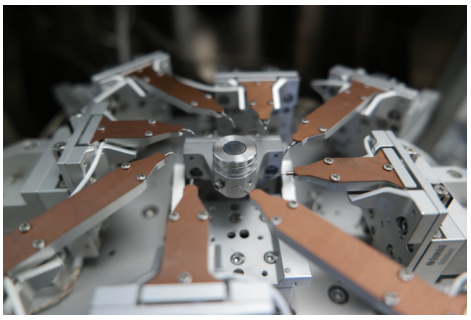
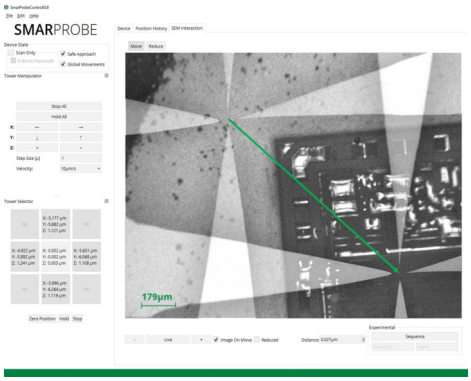


Figure 1. a*) Preparation of tungsten tips using the* **SMAR**PROBE *etch.* ***b****) Automatic positioning for needle exchange.* ***c****) Automatic positioning for sample exchange and subsequent referencing to a reproducible start position reduces the in-air time in between probing sessions.*

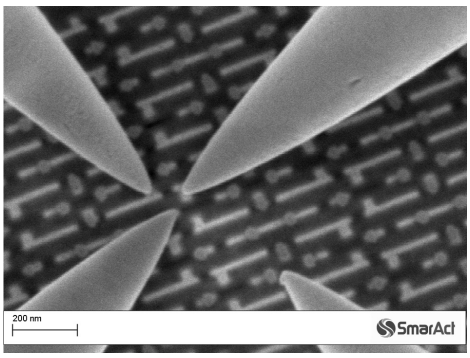
Setting up the probe tips. A short on-air time is also beneficial to achieve a low vacuum level within the time the **SMAR**PROBE *LX* reaches thermal stability, approximately one hour, and is ready for low-drift nanoprobing. The vacuum quality can be further improved by applying a mild plasma cleaning procedure which also cleans the sample surface

from carbon adsorbents. Carbon contamination of the sample surface and on the tips increases the contact resistance during probing significantly and should be avoided. To reduce the carbon deposition induced by the electron beam during imaging the following **SMAR**PROBE routine is recommended. First, all needles should be brought together within a 10 µm large circle, located away from the point-of-interest of the sample. This can be done very fast by using the *point&click* feature of the **SMAR**PROBE. With just one mouse click any tip can be selected and with a second click the tip can be moved to any point within the SEM. Now all the tips can be brought to the approximately same height using the focus information of the SEM, allowing the sample to be brought up until it is close to the tips. Each tip can be brought into contact with the sample surface by using the unique *safe approach* movement pattern and subsequently lifted by a defined distance of 1 µm. To increase the speed and the reliability of this step it is recommended to use the **SMAR**PROBE *advanced probe holder* which automatically brings the tip close to contact with the sample surface. Once the tips are close to surface it is easy to perform the cross-cleaning of each tip by using the pre-defined cross-cleaning procedure within the Keithley 4200 SMU. After the cleaning of the tips it is recommended to use the *point&click* feature to move the samples point-of-interest just below your probing tips as shown in Fig.Figure 2a. To avoid collision it is recommended to check that the surface at the point-of-interest is not higher compared to the surface below the tips. The **SMAR**PROBE software has an *image-on-move* feature which automatically makes an image after a *point&click* movement has finished, but pauses the imaging before and afterwards, which reduces the amount of carbon contamination and the electric charging of sensitive materials. Accurate positioning within this imaging mode is made possible due to the closed-loop active position holding of the manipulators.

(a) Tip Positioning via Point&Click



(b) Contacting



(c) I-V measurement

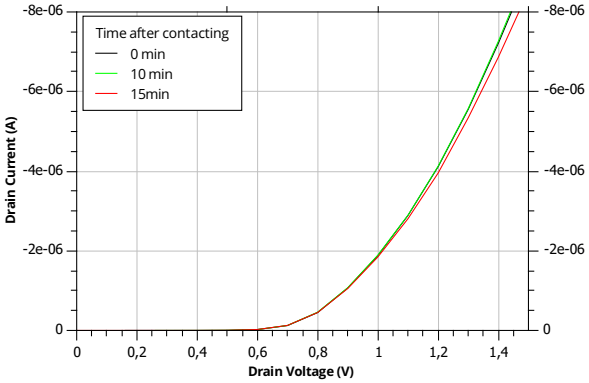


Figure 2. ***a****) Image of the* **SMAR**PROBE *graphical user interface. Key feature are point&click and image-on-move.* ***b****) Four nanoscopic tips contacting a transistor of a 14 nm technology node processor.* ***c****) I-V curve of the transistors drain contact measured against ground. The electrical contact between tip and drain contact is stable for around 15 minutes.*

Nanoprobing. Once a high resolution image of the tips around the point-of-interest has been taken it is easy to position the tips above the desired contact points using *point&click* movement combined with *image-on-move*. The lowering of the tips exactly onto the transistor pads is possible due to the true z-movement of the manipulators. An example of a transistor contacted by three tips is shown in Fig.Figure 2b. To check whether the tip is in contact with a transistor pad it is recommended to use the fast I-V measurement option of the SMU and lower the tip until you get the desired contact resistance. An example of such an I-V measurement is shown in Fig.Figure 2c. In case the sample is not sufficiently clean to get proper electrical contact it is recommended to in-situ clean the sample with a plasma cleaner or an ion-gun connected to the SEM, which however is not part of the **SMAR**PROBE system. From this point, probing several transistors is simple, the sample stage can be lowered by 1 µm and the *point&click* movement combined with *image-on-move* can be used to position the sample stage to the next transistor. Due to the very low thermal drift rate

($<$ 1 nm/min) and the active position holding (closed-loop), the position of the tips is almost unchanged and lifting the sample again by 1 µm will bring them back close to contact with the next transistor (*step&repeat*). The high repeatability of the sample stage will require re-adjustment of only a few nanometers. In the case of probing 14 nm transistor technology, a re-adjustment of the tip positions is necessary only every 15 minutes due to the low drift rate of the tips (see Fig.2c).

SUMMARY

In this application node the **SMAR**PROBE *LX* was used to probe a 14 nm technology node sample. It was shown how the closed-loop positioning allows the user to position the tips to the point-of-interest in very short time and with as little electron beam exposure as possible. The *safe-approach* movement and the large scan range will reduce the risk of damage to the tips and the sample during fine-positioning. The resulting longevity of the tips combined with the ability to load several samples gives the possibility to greatly improve the sample through-put. Please contact us to get more information about the probing system, the accessories or a complete system including an SEM.

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