

Micro Four-Point Probe General Application Note

CAPRES A/S
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App-0001-01-02

1 Introduction

The four-point probe is a well-known tool for performing reliable measurements of electronic transport properties in semiconductors. Conventional four-point probes are millimeter sized devices with spring loaded electrodes of tungsten carbide or similar hard materials. This chapter briefly introduces the four-point measurement technique, and introduces a Micro Four-Point Probe (MFPP).

1.1 The four-point measurement technique

A four-point measurement is performed by making four separate electrical connections to a sample, and driving an electrical current through two of these connections while monitoring the corresponding electrical potential at the other two connections. The typical setup for performing such a measurement is shown in figure 1.

The four electrodes are typically aligned in a row, and a current I is driven through the outer electrodes, while the four-point voltage V is measured across the inner electrodes using an electrometer. Since the input impedance of the electrometer is very high, the current running through the electrometer electrodes is negligible compared to the current running through the sample (originating from the outer current source electrodes). As a consequence the measured four-point resistance V/I does not contain any significant contribution from the contact resistance between the four electrodes and the sample. The four-point method is often used for resistivity measurements on semiconductors, where the contact resistance can be considerable.

1.2 The Micro Four-Point Probe

The Capres Micro Four-Point Probe (MFPP) has an electrode spacing three orders of magnitude smaller than conventional four-point probes. It is fabricated

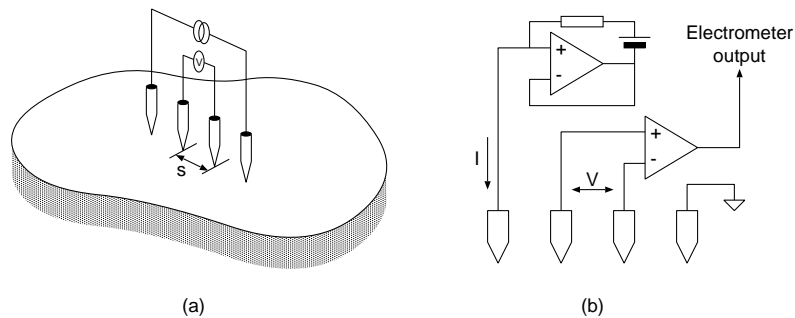


Figure 1: The four-point probe technique. (a) Typical four-point probe configuration. (b) Schematic of measurement electronics.

using silicon based micro-fabrication technology. Capres offers probes with a standard electrode spacing of 5, 10, 15, 20, 25 and 30 μm . Other probes are available on request, including 1.5 μm spaced four-point probes and multi-point probes.

Figure 2 shows a Scanning Electron Microscope (SEM) micrograph of the electrode area on a 10 μm spaced MFPP chip. The MFPP electrodes typically consist of 1 μm thick silicon oxide cantilevers with a conducting Cr/Au top layer of 25/100 nm (Cr is used for adhesion purposes) [1]. Other application specific conducting materials can be used as well.

In addition to the small electrode spacing, the MFPP also features a very low contact pressure compared to conventional probes. The cantilever spring constants are typically 1-10 N/m, enabling non-destructive measurements to be performed on a wide range of ultra-thin films. The MFPP is in fact designed for micro-scale electrical characterizations of ultra-thin materials, and is an ideal tool for quality control in the semiconductor and thin-film industries. It can also be used for more fundamental scientific studies, such as the resolution of electronic surface surface states on semiconductors [2].

2 Using the Micro Four-Point Probe

The MFPP is sensitive microscopic electro-mechanical device, and care must be taken to avoid damaging it. This chapter explains the safe use and storage of the MFPP, in order to help users maximize probe lifetime and measurement accuracy/repeatability.

2.1 The device

The MFPP consists of a silicon chip containing the integrated multi-point electrode structure (Figure 2), which is attached to a ceramic carrier with gold-plated electrodes, as shown in figure 3. The electrodes on the ceramic carrier

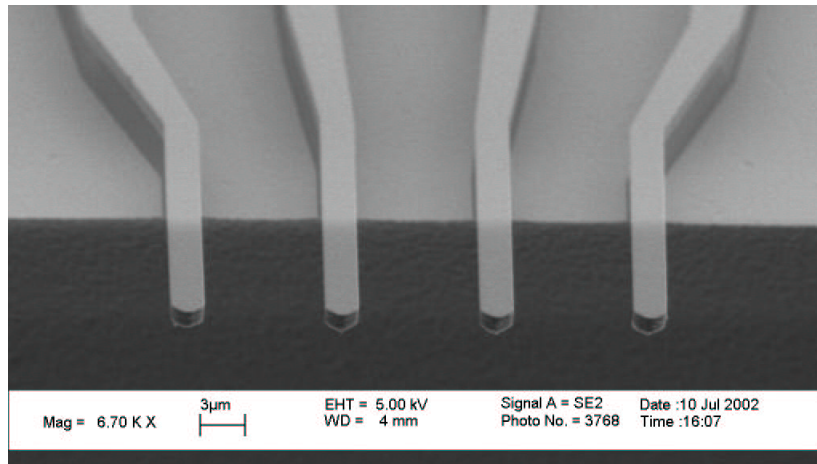


Figure 2: Scanning Electron Microscope (SEM) image of micro four-point probe with 10 μm electrode spacing.

form an edge connector. A matching female connector is available for making reliable electrical contact to the device. The electrodes on the ceramic carrier are connected to the silicon chip by means of bonded gold wires, which are visible as thin lines on the rightmost image in figure 3. The large number of electrodes on the ceramic carrier give ample room for future developments and compatibility with Capres multi-probes.

2.2 General usage and handling

The MFPP as shown in figure 3 is a very sensitive component, and care should be taken when handling the device. The most sensitive part is the microscopic probe cantilevers (Figure 2) which extend from the edge of the silicon chip, in the direction opposite of the carrier connector electrodes. Contact to this area must be avoided when handling the MFPP. In addition, most versions of the MFPP have unprotected bonding wires (for reasons of vacuum compatibility), that are easily damaged. The best way to safely handle the MFPP is to use a custom tweezer (available from Capres). With this tweezer the device can be held firmly by the edges of the ceramic carrier, without risk of damage to the component. Care should still be taken, however, to avoid chipping the ceramic by use of excessive force.

The MFPP is furthermore sensitive to electrostatic discharge, and the same precautions that apply to handling of normal electrostatic sensitive components should be observed. This includes use of ESD protective surfaces, dissipative wrist straps etc. Electrostatic discharge may cause the probe cantilevers to stick together, or may cause electrical breakdown internally on the silicon chip.

Dust particles or other contaminations on the MFPP cantilevers can be at-

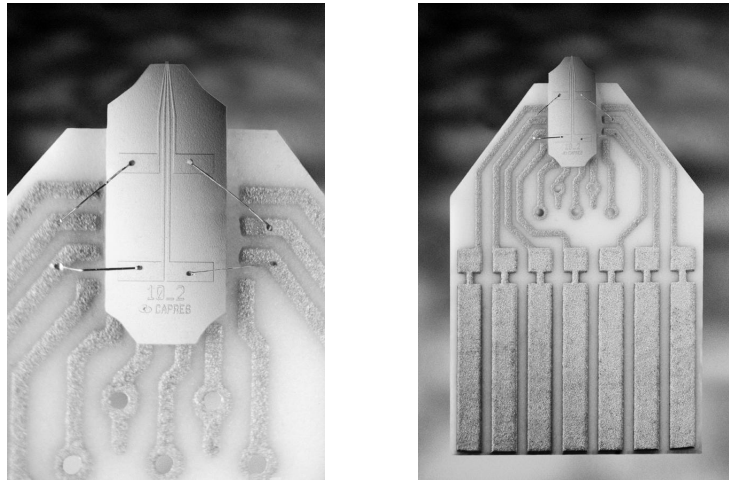


Figure 3: Micro four-point probe mounted on a ceramic carrier with thick-film electrodes.

tempted removed by a gentle flow of dry nitrogen or similar inert gas. Using a too strong flow can damage or even break the cantilevers. Applying any type of cleaning fluid directly on the silicon chip is not recommended, and will most likely ruin the device permanently.

The edge connector area on the ceramic carrier can if necessary be cleaned by wiping with a q-tip soaked in ethanol.

2.3 Storage

It is important that the MFPP remain protected from electrostatic discharge and dust at all times. The MFPP devices are normally packaged in quantities of five in ESD safe foam boxes, as shown in figure 4. It is recommended that the devices are kept in these original containers when not in use. Leaving probes unprotected under ambient conditions for extended periods of time should be avoided, as accumulated dust and other contaminations may degrade their performance significantly, or even ruin them completely. For longer term storage, it is best to place the MFPP containers in a nitrogen cabinet or a similar inert atmosphere.

3 The measurement setup

This chapter describes the mechanical and electrical considerations in a typical MFPP measurement setup.



Figure 4: Standard ESD safe MFPP storage boxes.

3.1 The mechanical interface

The MFPP is similar to the flexible needle probes used for Atomic Force Microscopy (AFM) [3]. In AFM, a sample surface is imaged by mapping the forces between a sharp tip and the surface. The AFM probes consist of a small substrate supporting a cantilever structure with a sharp protrusion at the end. Such an AFM cantilever design is shown in figure 5, together with the MFPP design. The most noticeable difference between the MFPP and AFM designs is the shape of the cantilever tips. The MFPP has in-plane tips made from tapered cantilevers, whereas AFM cantilevers contain very sharp out-of-plane protrusions which are needed to obtain high-resolution surface images.

The orientation of the MFPP with respect to a sample surface during measurements is somewhat different from the conventional AFM arrangement, since the MFPP tip is in the plane of the cantilever, not perpendicular to it as it is the case for AFM probes. In a typical AFM setup the angle between sample and cantilever is around 5° , as illustrated in 5(b). The MFPP requires a larger angle typically around 30° .

It is recommended that an MFPP setup includes a means for visual inspection, since it can be critical to observe the probe cantilevers as they press against a sample surface. Visual inspection also enables the identification of special surface features to be measured. The most simple way to achieve this is to fix the MFPP to a microscope objective in a position where the four cantilevers are in focus in the view-field of the objective. The MFPP should be mounted at an angle of 30° with respect to the sample surface, as shown in figure 5(d). The microscope objective can then be moved towards the sample until the sample surface comes into focus. At the same time the MFPP

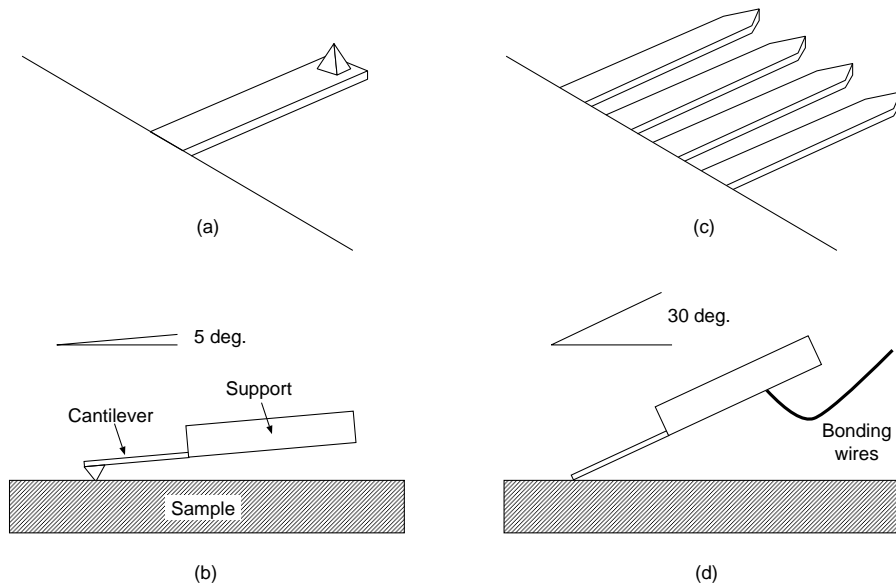


Figure 5: (a)-(b): Typical AFM (Atomic Force Microscopy) probe-sample configuration. (c)-(d): MFPP probe-sample configuration.

electrodes will touch the sample and electrical contact is established.

Once electrical contact to the sample surface has been established, the MFPP should be moved a small distance further towards the sample surface. This overdrive ensures that good electrical contact between the probe and the sample is established. The necessary overdrive depends on the MFPP electrode dimensions and the sample surface conditions, but is typically in the range of 0.1 to 2 μm . The cantilevers can be permanently damaged or destroyed if the overdrive is too big. A strong change in cantilever reflection is typically visible when the overdrive is too large. Interference fringes (Newton's rings) can also appear.

3.2 The electrical interface

A minimal electronic interface consists of a current source connected to the outer MFPP electrodes and an electrometer / nanovoltmeter connected to the inner electrodes, as shown schematically in 1(b).

For very low current measurements it is important to have as large an input impedance of the electrometer as possible. The impedance can be increased by putting two instrumentation amplifiers in series across the inner probes [4]. This is however not needed at typical current levels.

Care should be taken to limit the current when the probe is brought in and out of contact with the sample surface. The cantilever electrode material can melt if the current is too high at this moment. This effect is often visible optically

as dark spots appearing on the outermost current carrying electrodes, and will typically result in failure of the device.

It is often advantageous to use a lock-in (AC) technique for performing the MFPP measurements. This can be done by applying a oscillating reference signal to the outer probe electrodes, while measuring the in-phase component of the potential across the inner electrodes. This method can give very accurate resistance measurements [5], and if the frequency of the reference is kept sufficiently low, the measurements can still be considered effectively DC.

4 Troubleshooting

This chapter describes a number of known caveats and special considerations that may help the MFPP user to better understand and improve performance of an MFPP measurement setup.

4.1 Mechanical issues

4.1.1 Vibrations

The mechanical stability of the setup is very important in order to make reliable measurements. The MFPP is sensitive to small changes in the cantilever positions on the samples surface, and nano-meter scale variations in position and/or contact area can lead to large (5-10%) variations in the measured resistivities. The best stability is obtained using air-suspension or similar vibration reduction, and avoiding placing the setup near sources of mechanical noise (such as rotary pumps). Another important source of vibration to limit is acoustics (sound) and air turbulence from air-conditioners, blowers, fans etc. The best way to eliminate this type of vibration is to perform the measurements in an enclosure.

4.1.2 Drift

If measurements require the MFPP to remain in contact with the sample surface for longer periods of time, it is important to minimize the mechanical drift between probe and sample. This drift can cause measurements to change over time and the probe may eventually crash onto the surface, or alternatively loose contact to the sample. This is best dealt with by making a compact measurement system with a short physical path between the probe and the sample, and by taking steps to avoid thermal fluctuations during the measurements.

4.1.3 Contamination

Contamination of the MFPP cantilevers can lead to degraded performance and can eventually render the probe useless. Contamination of the cantilevers typically originates from debris on the sample surface. Once particles touch the

electrode tips they will experience an electrostatic attraction, and will be very difficult, if not impossible, to remove. To avoid this, make sure that the samples are thoroughly cleaned before measurements are performed, for example using suitable solvents and ultrasonics. The measurement should be performed in a dust free environment to prevent that sample and probe contaminate over time.

4.2 Electronic issues

4.2.1 Noise

Electrical noise can be minimized by using short electrical connections (1-10cm) between the MFPP and the current-source/electrometer construct. Avoid very long unshielded wires. The noise can be further reduced by using a lock-in based technique.

4.2.2 Grounding

Always make sure that the setup is properly grounded. Poorly or wrongly (looped) grounded systems may cause spurious effects in the measured data, and floating potentials can suddenly cause large currents to flow through the MFPP cantilevers, melting the metallization, and destroying the device. All four cantilevers will typically be affected by this type of problem.

4.2.3 Current breakdown

If the four-point current is too large the MFPP might be damaged due to heating/melting of the two current-carrying cantilever electrodes. In particular, the sudden change in resistivity that occurs when the MFPP is brought in and out of contact with a sample surface may lead to overshoot in the current source and cause breakdown in the MFPP. This effect can also lead to similar damage in the sample area beneath the probe electrodes. Make sure that the current is completely off or very low when moving the probe. Only set the measurement current when the probe has been brought into full contact with the sample surface.

4.2.4 Voltage breakdown

Breakdown can also occur if a too large voltage is applied to the current carrying electrodes. The maximum voltage is around 10 V. Larger voltages are likely to cause permanent breakthrough on the MFPP chip. Care should in particular be taken when using standard electrometer and current sources, as they are normally slow devices that may significantly overshoot current and voltage settings when an abrupt resistance change is introduced. Read the documentation that came with such instruments carefully before attempting to use them with the MFPP.

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