Nanoprobing inside the SEM

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Abstract

Sharp metal tips with a radius of about 50 nm can be made by electrochemical etching. In our probe station, up to six probes can be independently manipulated with a joystick with about 1 nm resolution. The probes can be used to make electrical measurements like electron beam induced current (EBIC) measurements or voltage contrast imaging. They can also be used to modify the sample by scratching or pushing structures, small particles or carbon nanotubes around. By lifting a tip from a conducting surface it is also possible to generate a spark that ablates material away (micro electric discharge machining). Craters with diameters between 200 nm and 5 microns can be made. These probes are being used to construct and to measure the characteristics of nanodevices.

Voltage Contrast Imaging

Voltage contrast imaging in a scanning electron microscope (SEM) is a technique for studying potentials and potential distributions on a sample. The principle of voltage contrast is that secondary electrons at a conducting surface cannot escape the electric field produced when the metal is positively biased. Here we used it for visualizing a p-n junction across a cleaved surface of a doped silicon die. We placed two tungsten tips on each side of the p-n junction and applied a voltage of 10 V across the sample. The positive biased side appears darker in the secondary electron image.

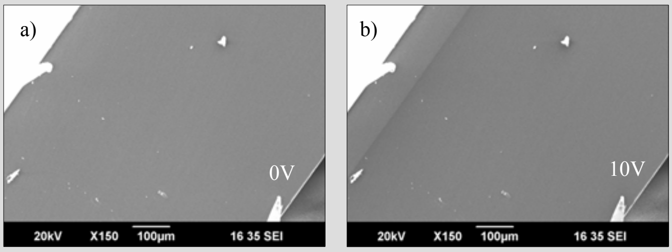

Fig. 3: a) SEM image of a cleaved surface of a piece of silicon with two tungsten tips landed near the edges. b) Applying a voltage of 10 V between the tips reveals a p-n junction in the silicon.

Micro Electric Discharge Machining (µEDM)

EDM is a method of removing material by electric arcing discharges between an electrode (the cutting tool) and a conducting work piece, in the presence of an energetic electric field. With our micromanipulators we are able to downsize this process and cut for example metal lines in an integrated circuit. Here we show aluminum lines on a silicondioxide substrate, which were cut by µEDM. We placed a 1 mH inductor and a 1 kΩ resistor in series with the needle and purposefully retracted the needle to cause a spark. Voltages of no more than 10 V were applied before the needle was retracted. Under these conditions, a maximum of 5×10^{-8} J of energy was stored in the inductor. When contact between the needle and the film was broken, the energy stored in the inductor created an electrical discharge that ablated the metal away near the point of contact.

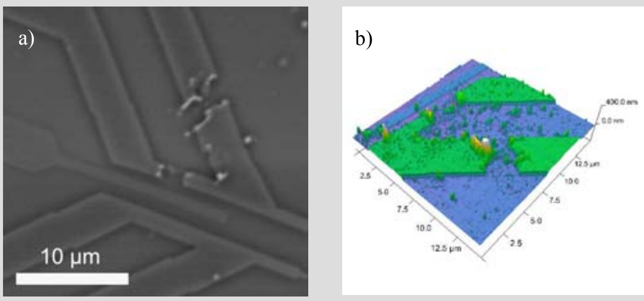

Fig. 4: SEM image (a) and AFM image (b) of cutted aluminum lines through µEDM. Line height is 80 nm and widths are 1,4 and 3,7 µm respectively.

Micromanipulator Probe Station

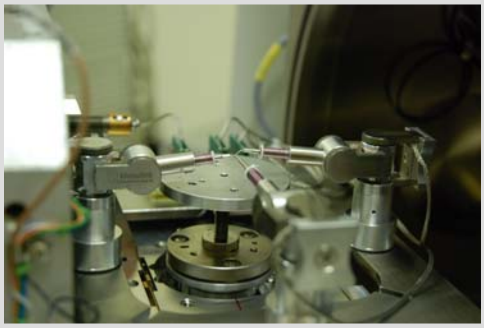

Fig. 1: Micromanipulator installed in a FEI Quanta 200 (photograph taken by Kleindiek)

EBIC Measurements

Electron beam induced current (EBIC) is used as an analysis tool in semiconducting devices. Due to internal electric fields (depletion region at a p-n junction or Schottky junction) electron–hole pairs, which are generated by the e-beam, will be separated. If the p- and n-sides (or semiconductor and Schottky contact, in the case of a Schottky device) are connected through a current probe, a current will flow.

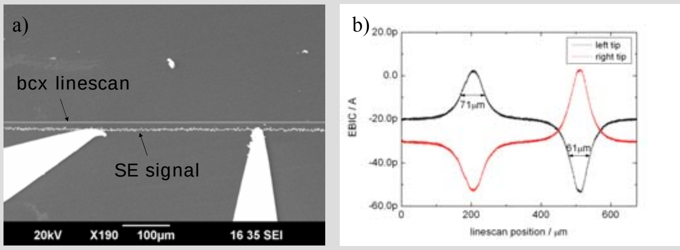

Fig. 2: a) SE image of two grounded tungsten tips on a p-doped silicon substrate. During the EBIC measurement the electron beam was scanned along a line across this image passing the tips close by. The position of the linescan and the SE detector signal of the linescan are shown. b) Graph of the EBIC signal of the two tips over the linescan position. The peaks, which are situated at the tip positions are indications of Schottky barriers of the contacts. The FWHM values for the peaks of the left tip are 71 µm and 61 µm respectively.

Microassembly

With micromanipulators it is also possible to manipulate micro- and nanocomponents like carbon nanotubes. Attached to the tip, they can be used for probing, but they can also be used for larger nanotube assemblies.

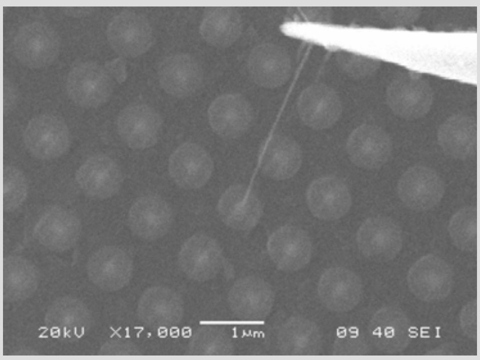

Fig. 5: A better probing resolution was achieved by attaching a multiwalled carbon nanotube to the tip with e-beam assisted carbon deposition.