# Quantitative Scanning Capacitance Spectroscopy

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In this work, we introduce a setup for quantitative scanning capacitance spectroscopy on nanoscopic scales. The setup consists of a commercially available atomic force microscope (AFM) for tip positioning. An ultrahigh precision capacitance bridge measures the tip-sample capacitance in the aF regime under well controlled, small signal conditions. This is a big advantage over commercial scanning capacitance microscopes (SCM) which work in the large signal regime and provide a signal that is the first derivative of the capacitance (dC/dV). To guarantee a constant tip-sample contact area we used highly doped, conductive diamond tips because of their high resistance against abrasion. As samples, we used low p-doped Si wafers covered with two types of dielectrics: industry quality $SiO_2$ and metal-organic chemical vapor deposition grown $ZrO_2$.

To test the reliability of our results, both macroscopic measurements on large area 100 $\times$ 100 $\mu m^2$ MOS capacitors with Al top electrode, and AFM based nanoscopic investigations were carried out on identical pieces of samples. In Fig. 1 (a), a comparison between the C(V) data of a reference MOS capacitor, and a nanoscopically measured C(V) curve is shown. An interface charge density $Q_{it}$ of about $5\times10^{11}$ $cm^{-2}$ can be calculated from the slope of the macroscopic reference curve. The smaller slope of the nanoscopic curve is due to the very small area of the AFM tip and a correlated high influence of electrostatic edge effects in the area of the tip. Figure 1 (a) can be used to calculate the work function $W_{tip}$ of diamond tips: $W_{tip} = \Delta W + W_{Al} = 5.5$ eV, where $\Delta W = e \times \Delta U$ is proportional to the voltage difference $\Delta U$ in Fig. 1 (a) and $W_{Al}$ =4.2 eV is the known work function of the Al top electrode. $W_{tip}$ = 5.5 eV is in agreement with the value of 5.165 eV found in literature for highly p-doped, deposited diamond.

The setup is also capable of measuring details of the interface trap energy distribution. This is shown by a comparison of macroscopic and nanoscopic capacitance measurements on a $ZrO_2$ covered Si sample in Fig. 1 (b). Interface traps lead to a decrease of the slope of the C(V) curve. If most of the interface, traps are activated within a small energy interval, the transition between accumulation and depletion in the C(V) curve contains regions of reduced slope or kinks. Both the macroscopic reference curve as well as the nanoscopic C(V) curve in Fig. 1 (b) exhibit a pronounced kink, which demonstrates that both curves have a comparable energy resolution. Such measurements are currently not available with standard commercial SCM equipment because of the large modulation voltages. This is demonstrated in Fig. 1 (c) where the nanoscopic dC/dV curve shows more features then the standard SCM curve. The nanoscopic C(V) curve was numerically differentiated to obtain the dC/dV curve in Fig. 1 (c).

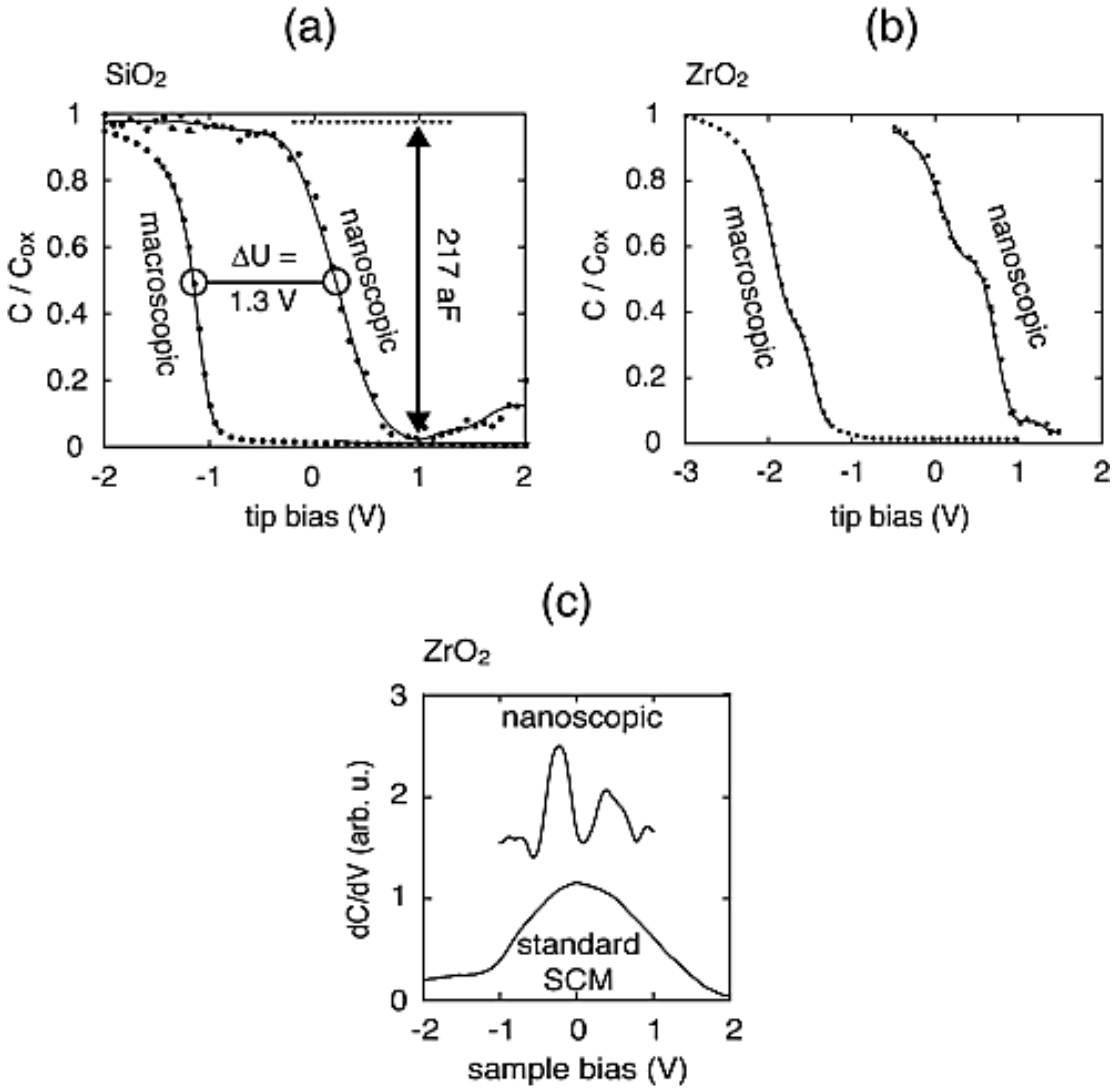


Fig. 1: (a) Comparison of a macroscopic and a nanoscopic C(V) curve on a $SiO_2$ covered sample.
(b) Comparison of the energy resolution of macroscopic and nanoscopic C(V) curves on a $ZrO_2$ covered sample.
(c) Comparison of a (derivated) nanoscopic capacitance curve and data obtained by standard SCM equipment.