ZrO_2 as Dielectric Material for Device Characterization with Scanning Capacitance Microscopy

W.Brezna[a], S.Harasek[a], H.Enichlmair[b], E.Bertagnolli[a], E.Gornik[a], J.Smoliner[a]

[a] Institut für Festkörperelektronik, TU-Wien
Floragasse 7, A-1040 Wien, Austria

[b] Austria Mikro Systeme International AG,
Schloss Premstätten, A-8141 Unterpremstätten, Austria

Scanning Capacitance Microscopy[1] (SCM) is an extension of conventional Atomic Force Microscopy (AFM) and a promising tool for semiconductor device characterization. Up to now, quantitative, reproducible measurements of doping profiles are a serious problem, because high quality dielectrics have to be deposited on the sample. Standard high temperature industrial silicon oxides cannot be used because the high temperature broadens all doping profiles in the underlying device. Low temperature or native silicon oxides are too bad in quality to be used in quantitative SCM measurements. For this reason, we replaced the SiO_2 with high quality, low temperature CVD grown ZrO_2.

A big advantage in using ZrO_2 as a dielectric material for SCM turned out to be its high stability against electrical stress. The images in figure 1 compare a SiO_2 and a ZrO_2 sample, which were stressed by scanning at a tip-bias of V_{tip}=-3 V. After 8 scans (scan area = 500 nm x 500 nm) the resulting degradation was investigated by taking 5 µm x 5 µm large images in capacitance mode. Severe degradation occurred in the stressed (dark) area in figure 1 (a). As one can see in figure 1 (b), ZrO_2 turns out to be insensitive to electrical stress. Only a slight increase in the SCM signal is observed in the treated region due to abrasion induced reduction of the ZrO_2 layer thickness.

One of the most important parameters describing the oxide quality both for SCM analysis is the amount of fixed oxide charges and interface trapped charges. According to MOS theory textbooks[2,3] these parasitic charges influence the shape of the capacitance signal versus voltage (C(V)) plots or the deviations dC/dV of it. Large amounts of fixed oxide charges move the C(V) curves horizontally from their corresponding flatband position to negative or positive tip-bias values, because the fixed charges have to be compensated. The shape of the curves remains unchanged. On the other hand, a large amount of interface trapped charges does not alter the voltage position of the C(V) curves, but smears them out and broadens the corresponding peak in the dC/dV curve. Typical dC/dV data measured with our SCM are shown in figure 2. It can be assumed that in the case of an ideal oxide, the flatband condition will occur near zero bias[2]. Therefore, the measured flatband bias, approximately indicated by the peak positions in the dC/dV curves, should theoretically occur near V_{tip}=0 V. As one can see in figure 2, ZrO_2 has its dC/dV maximum at +0.18 V and the high temperature SiO_2 sample at -1 V, which demonstrates the low density of fixed charges in our ZrO_2 films. In addition, the peak of the ZrO_2 covered sample is narrower than the peak of the SiO_2 covered sample, which means that there are also less interface traps in ZrO_2 than in SiO_2.

To demonstrate the utilization of ZrO_2 as a dielectric material for SCM supported device analysis we finally compare SCM images of pn-junctions covered with industrial high-quality SiO_2 and CVD-grown ZrO_2, respectively. As one can see in figure 3 (a), ZrO_2 can compete easily with the SiO_2 layers concerning contrast generation. The differences in the width of the n-doped regions in figure 3 (a) and (b) is due to slight deviation from the tip-voltage which would maximize the SCM signal. It is known that the tip-bias dependent surface potential has a major influence on the carrier concentration in the vicinity of pn-junctions, and therefore the measured junction-positions can differ when the applied tip-biases do not create exactly the same surface potential in figure 3 (a) and (b)[4].

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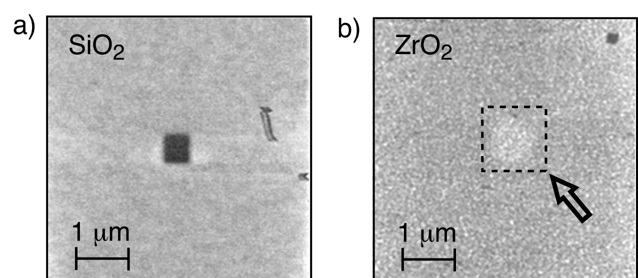

Figure 1. SCM image of the stressed region of (a) a SiO_2 covered sample and (b) a ZrO_2 covered sample. The scan size of both images is 5 µm x 5 µm.

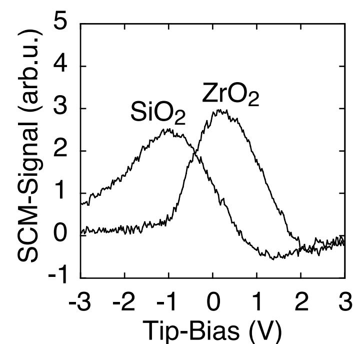

Figure 2. dC/dV curves of homogenously doped samples (N_A=9.4 x 10^{14} cm^{-3}) which were covered with ZrO_2 and SiO_2, respectively.

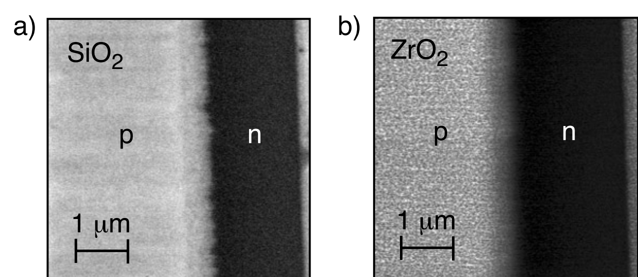

Figure 3. SCM images taken on (a) SiO_2 and (b) ZrO_2 samples, respectively. The scan area was 5 µm x 5 µm for both images. The sample surface is on the right side.