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Measurement of extension structures in deep sub-micron MOSFETs by scanning capacitance microscopy based on frequency modulation control

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1. Introduction

As the size of semiconductor devices reduces, 2-Dimensional (2-D) dopant profiling for the cross-sectional S/D-extension region of the MOSFET structure becomes an important task to provide process technology on a nano-meter scale. Scanning capacitance microscopy (SCaM) is promising since its well-known dC/dV response yields an image sensitive to a 2-D dopant profile [1]. However, the practical use of SCaM is rather limited since the conventional metal-coated probe is easily degraded during scanning, sometimes even within one frame. Probe-sample gap control in SCaM, by either contact or tapping mode, requires that the probe contacts more or less hardly to the sample, which degrades the probe apex. In this study, we report a new SCaM using ***an all-metal probe*** [2] where the gap to the sample is controlled by a self-oscillation frequency shift. In other words, it is a frequency modulation (FM) technique [3] working at a very weak probe-sample interaction. FM-SCaM allows more stable imaging and has a resolution up to ~7 nm for dC/dV images. FM-SCaM has been applied to profile 2-Dimensionally the S/D-extension region of the MOSFET structure. We obtained channel length, gate length, and gate-extension overlap length, as a function of the pocket implant dose, which shows the potential of FM-SCaM for extension/channel engineering.

2. Experimantal

Figure 1 shows a block diagram of FM- SCaM. The probe was a sharpened tungsten wire attached to a high Q quartz tuning fork to give it an oscillation vertical to the sample, i.e., tapping mode. Probe motion is monitored electromechanically, without using an optical setup.

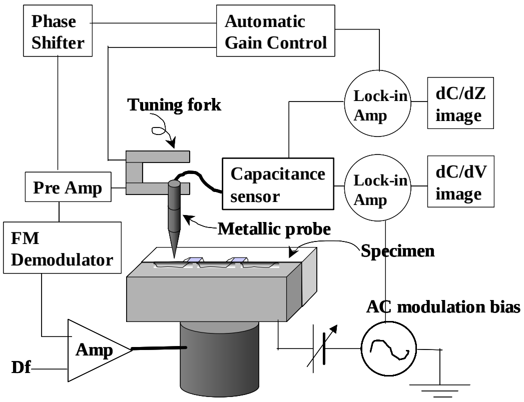

Fig. 1. Schematic Diagram of FM-SCaM

FM- SCaM simultaneously images two electrical signals, dC/dz and dC/dV. The dC/dV images were acquired under no DC bias, and an AC bias of 0.4 V in amplitude at 700 kHz. The dC/dZ image gives information emphasizing the local capacitance of the sample. All samples were cleaved for cross-sectional imaging. Before the measurements, the cross sectional surface was air-baked, and illuminated by vacuum ultra-violet (VUV) light to make a thin, uniform oxide layer [4]. Samples were p-MOSFET with different pocket implant doses, as summarized in Table 1.

3. Results and Discussion

Figure 2(a) shows the dC/dV image and 2(c) the dC/dZ image of a p-MOSFET of sample 1 obtained simultaneously by FM-SCaM. The scanning area is about 0.6×0.6 μm. In Fig. 2(a), n-type regions appear dark and p-type regions light. The p-n junction is observed as dark stripe-like features, and the depletion region is observed as the white region around the p-n junction. The dC/dV signal detects a capacitance modulation of the MOS structure composed of metallic probe and sample. Thus in a highly doped region, the dC/dV signal becomes small and its S/N deteriorates, as is shown in Fig. 2(a). Figure 2(b) shows the profile for the line A-A' in Fig. 2(a). The profile indicates an abrupt change in dC/dV signal between the channel region and the deep S/D region. The spatial width of this abrupt change is about 7 nm.

The highly doped region in the deep S/D and the gate electrode are clearly visualized in the dC/dZ image in Fig. 2(c). Figure 2(d) shows the result of a synthesis of the dC/dV image and the dC/dZ image. This synthesized image enables to extract characteristic parameters such as channel length, gate length, and gate-extension overlap length.

The synthesized dC/dV and dC/dZ images of Fig. 3(a) to (c) correspond to the samples 2 to 4, respectively. These images clearly show that the profile of the extension region is affected by the degree of pocket implant dose. Figure 4 summarizes the relationship between pocket implant dose and extension depth, extension-gate overlap length, which were extracted from Fig. 3(a) to (c). The extension depth, extension-gate overlap length decreased by increasing the pocket implant dose. They are linear functions of this dose.

4. Conclusion

The 2-D extension profile in the cross-sectional p-MOSFET structure was investigated by FM- SCaM as a function of the pocket implants dose conditions. The FM-

SCaM simultaneously gives two kinds of images, dC/dZ and dC/dV. The former allows viewing the gate electrode structure and the latter the p-n junction loci in 2-D. The extension depth and the extension-gate overlap are thus directly obtained from the dC/dZ and dC/dV images, and found to be linear functions of the pocket implant dose. This 2-D information provides useful parameters for process simulation.

TAble. 1. pocket dose condition of sample 1 to 4

Sample No	1	2	3	4
Dose of pocket implants	non	2E13cm^{-2}	1E13cm^{-2}	5E12cm^{-2}

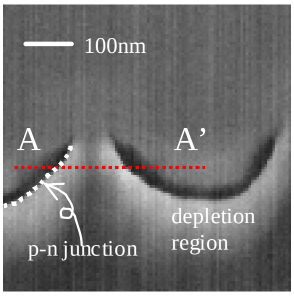

Fig. 2(a) A dC/dV image of sample 1 obtained by FM- SCaM

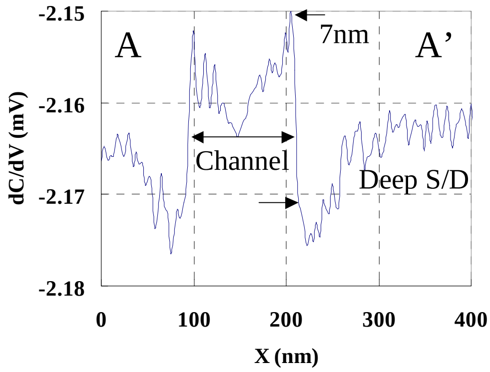

Fig. 2(b) A profile along a line A-A’ in Fig. 2(a)

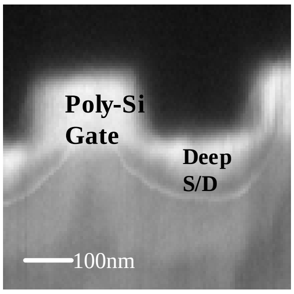

Fig. 2(c) A dC/dZ image of sample 1 obtained by FM- SCaM

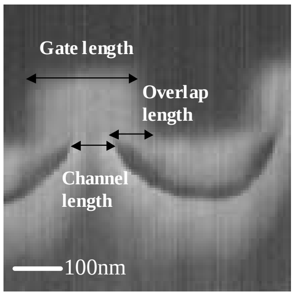

Fig. 2(d) An image synthesized from dC/dZ and dC/dV images for sample 1

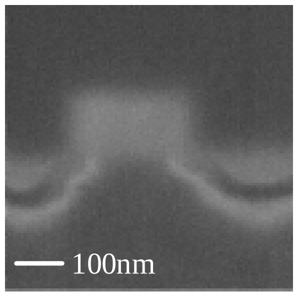

Fig. 3(a) An image synthesized from dC/dZ and dC/dV images for sample 2

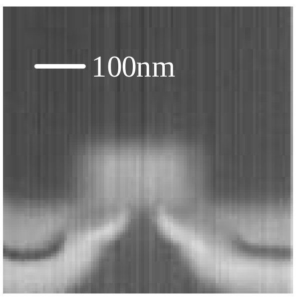

Fig. 3(b) An image synthesized from dC/dZ and dC/dV images for sample 3

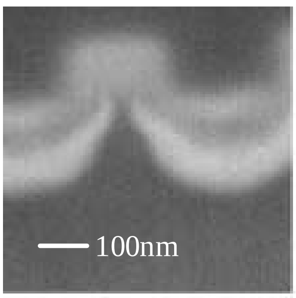

Fig. 3(c) An image synthesized from dC/dZ and dC/dV images for sample 4

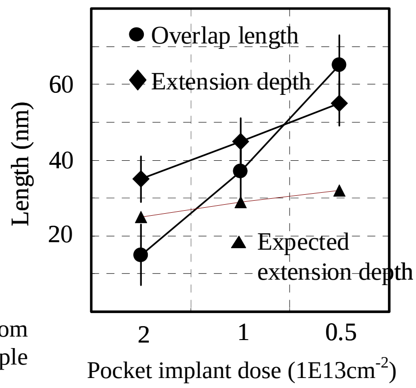

Fig. 4 Dependences of extension parameters on the pocket implant dose.

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