Investigation of DC and Low Frequency Noise Parameters of Junctionless GAA Si VNW pMOSFETs in the Temperature Range from 80 K to 340 K

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In this article, junctionless vertical nanowire (JL VNW) Gate-all-around (GAA) silicon field-effect transistors (FETs) manufactured at imec have been studied, in a wide range of temperature from 340 K down to 80 K, by performing direct current (DC) and low-frequency noise (LFN) measurements. The aim of this experimental study is to investigate the temperature dependence of the extracted DC parameters (low field mobility (μ_0), threshold voltage (V_{th}), access resistance (R_{access}), subthreshold slope (SS) etc.), and LFN parameters (flicker (1/f) noise level, volume trap density N_{it}, etc.), for the studied devices in order to evaluate their performance. The investigated devices are silicon NWs with a diameter of ~18 nm and a length of ~56 nm, which have been epitaxially grown on Silicon-on-Insulator (SOI) substrate. They are B-doped, JL and asymmetric ($R_{Drain} \neq R_{Source}$) devices, more fabrication details can be found in [1]. Two different devices were tested, devices #1 have 20 by 20 NWs in parallel while devices #2 have 30 by 40 NWs resulting in total 400 NWs and 1200 NWs for device #1 and #2 respectively. The measurements were made in ohmic regime with a drain-source bias of $|V_{DS}|$ = 50 mV, in forward and reverse (F/R) operation mode. The experimental set-up and the parameters extraction methodology are described in [2,3]. According to the figures 1.a and 1.b (device #2, $|I_{D,(F/R)}|$ *vs.* $-V_G$ curves) an increase of leakage current in forward operation mode is observed, which may testify that, it suffers from the GIDL effect [4], due to the high doping concentration of the drain and/or the S/D asymmetry. From figure 1.c, a decrease in $|I_{D,ON}|$ for lower temperature (T), may be observed and no zero-temperature coefficient (ZTC) point was observed in the investigated temperature range. However, a better SS was perceived for lower temperatures until T = 120 K as illustrated in figure 2.a. In figure 2.b, Vth is negatively shifted with a slope of about -1.3 mV/K. A significant degradation of the low field mobility is noticed as the temperature decreases. It may be suggested that scattering by surface oxide charges may be the dominating mechanism causing μ_0 degradation as can be observed in figure 2.c, since the evolution of the extracted μ_0 is proportional to the temperature [5]. It is important to note that a decrease in the extracted R_{access}, when the temperature decreases was also observed for both devices, see Figure 2.c (right). On the other hand, the LFN measurements reveal an increase in the input referred noise power spectral density (PSD) as the temperature decreases for the same $|V_{ov}|$, ($|V_G$-Vth$|$) as illustrated in figure 3.a. Figure 3.b shows the 1/f noise level *vs.* $|V_{ov}|$ for device #1. For T = 300 K, the dominant noise contributions are the correlated carrier number and mobility fluctuations mechanism (CMF + CNF), and the R_{access} noise contribution at high $|V_{ov}|$ values, (no impact of the S/D asymmetry was observed on the LFN). For T = 150 K and 80 K only CMF + CNF was observed, which may be related to the decreasing of the R_{access}. A correlation was fond between mobility μ_0 degradation and the estimated flat-band noise level (S_{vfb}) and N_{it} increasing as exposed in figure 3.c. This correlation suggests an impact of the charge oxide traps on both 1/f noise level and low filed mobility through remote Coulomb scattering.

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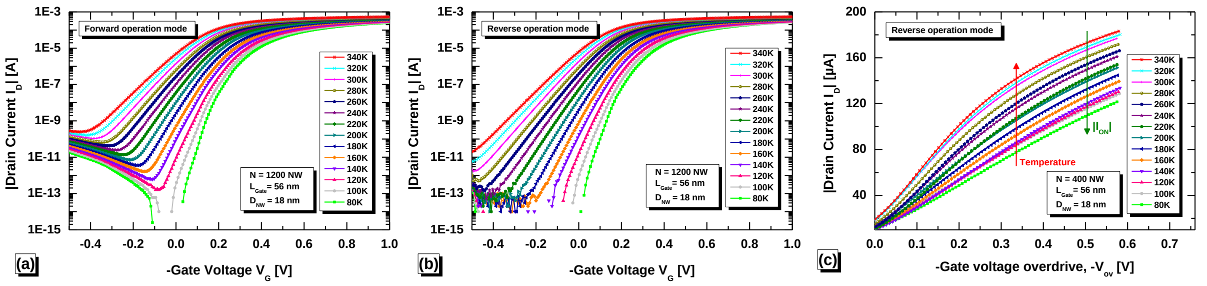

Figure 1: Absolute drain current $|I_D|$ *vs.* - applied gate voltage in forward (a) and reverse (b) operation mode (in log scale) as a function of temperature for device #2 (1200 NWs). (c) Absolute drain current $|I_D|$ (in linear scale) *vs.* absolute gate voltage overdrive $|V_G\text{-}Vth|$ for device #1 (400 NWs) as a function of temperature.

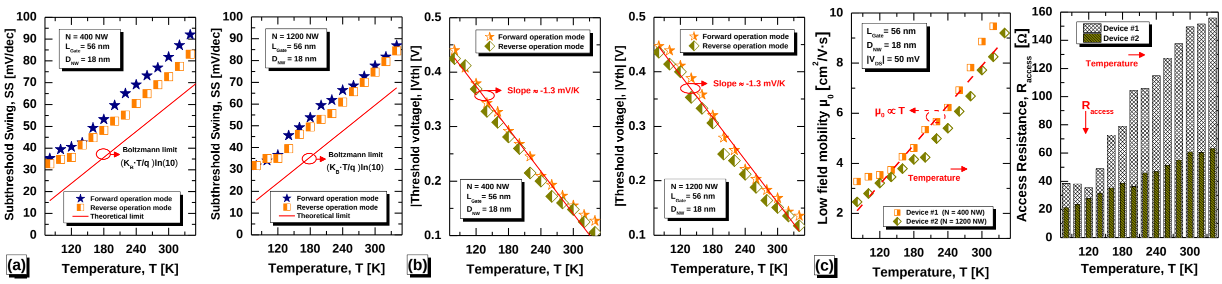

Figure 2: (a) SS as a function of temperature for device #1 (left) and device #2 (right). (b) Threshold voltage Vth as a function of temperature with $|V_{DS}|$= 50 mV. (c) Extracted low field mobility parameter μ_0 (left) and access resistance $R_{accesss}$ (right) *vs.* temperature for the studied devices.

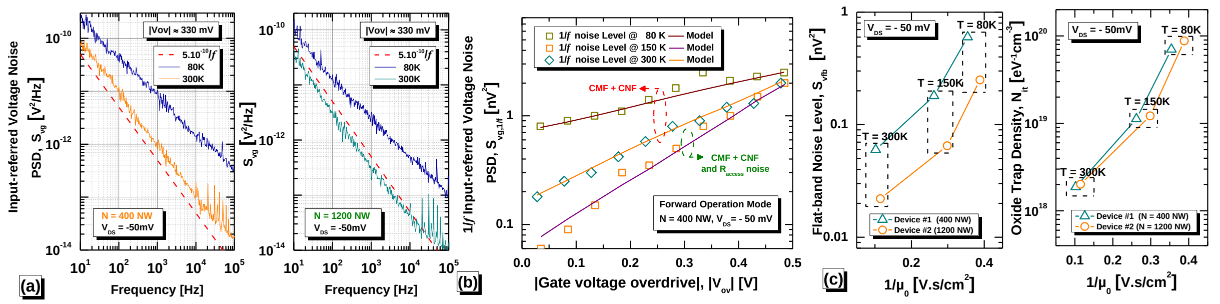

Figure 3: (a) typical 1/f input-referred voltage noise PSD S_{vg} *vs.* frequency for different temperatures at $|V_{ov}| \approx$ 0.330 V and V_{DS} = -50mV for device #1 and #2. (b) Input-referred 1/f noise level *vs.* the gate voltage overdrive (V_{ov}), for temperatures T=300 K, 150 K and 80 K for device #1. (c) Estimated flat-band noise levels (left) and N_{it} (right) *vs.* the inverse of the extracted low field mobility for T = 300 K, 150 K and 80 K for device #1 and #2.