Effects of Channel and Crystalline Orientations on the Electron Mobility in MOSFETs Fabricated on (114) and (5 5 12)-Silicon Substrates

M. Castro-L1, F. J. De la Hidalga-W1, P. Rosales-Q1, A. Torres-J1, W. Calleja-A1, E.A. Gutiérrez-D1, and D. L. Kendall2
1Electronics Department, INAOE, Puebla, México
2StarMega Corp, Albuquerque, NM 87123, USA

This work reports the measurement of the electron mobility in the inversion layer of MOSFETs fabricated on Si(114) and Si(5 5 12), for medium and high effective transverse electric fields, $E_{\text{eff}}$. These substrates were chosen because their surfaces present row-like features with a relatively long (1-digit nanometers) inter-row periodicity [1-2] that could be used to develop nm-like MOSFETs. We studied the channel mobility in these surfaces as a function of the channel direction [1-4].

N-channel MOSFETs were simultaneously fabricated on (001) (used as a reference), (114), and (5 5 12) Si wafers. The channel was oriented at 0, 15, 30, 45, 50, 75, and 90° away from $[1\overline{1}0]$ $\bar{1}$. We measured the channel conductance $g_d$ in W/L=45$\mu$m/45$\mu$m MOSFETs operating in the linear region ($v_{ds}$=50 mV), and the effective mobility, $\mu_{\text{eff}}$, was calculated as [5]:

$$\mu_{\text{eff}} = \frac{L_{\text{eff}} g_d}{W_{\text{eff}}} \frac{1}{Q_n}$$

As can be seen in Fig. 1 for the (114)-MOSFETs, the effective mobility decreases as the angle of the channel with respect to the $[\bar{1}10]$ direction varies from 0° (parallel) to 90° (perpendicular to the nanogrooves); this behavior was similar to that obtained for the (5 5 12)-MOSFETs. These results mean that, in opposition to the isotropy found in (001)-MOSFETs (where the dependence of mobility on the channel angle was practically null), the channel electron mobility in these specific high index Si substrates is highly anisotropic at any $E_{\text{eff}}$. Thus, the surface roughness scattering is the dominant process and it depends strongly on the channel orientation. This fact can be explained by the peculiar row-like surface topography with quite regular nanogrooves running along the $[\bar{1}10]$ direction. We believe that these nanogrooves can also behave as nanotubes, thus improving the carrier transport when the MOSFET channel runs along this direction; on the other hand, the roughness scattering is enhanced when the channel is tilted away the $[\bar{1}10]$ direction, thus degrading the mobility.

Fig. 2 shows a comparison of the highest mobility measured (channel oriented at 0°) for the three substrate orientations used in this work. For $E_{\text{eff}} \sim$1MV/cm, the electron mobility in Si(5 5 12) is as high as the mobility in Si(001), whereas the mobility for (114)-MOSFETs is even higher. This fact can be of great technological relevancy since in current MOS technologies is common to find oxide thicknesses of the order of 2-3 nm and gate voltages of around 1 volt, which leads to $E_{\text{eff}} >$1MV/cm.

At the time of the conference the results will be discussed in terms of phonon and surface scattering mechanisms, and a single model for effective electron mobility in these orientations will be proposed.

**Fig. 1.** Effective electron mobility as a function of the channel direction for (114)-MOSFETs. The mobility behavior is similar for the (5 5 12) case.

**Fig. 2.** Electron mobility as a function of the crystal orientation for channels oriented at 0°.

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**References**