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

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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_{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 $[\bar{1}10]$. We measured the channel conductance g_{d} in W/L=45μm/45μm MOSFETs operating in the linear region (v_{ds}=50 mV), and the effective mobility, μ_{eff}, was calculated as [5]:

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

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_{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_{eff} ~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_{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.

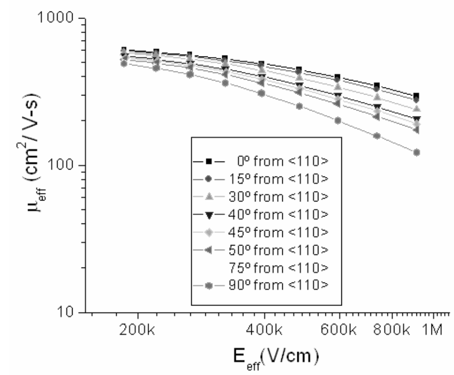

Fig. 1. Effective electron mobility as a function of the channel direction for (114)-MOSFETs. The mobility behavior is similar for the (5 5 12) case.

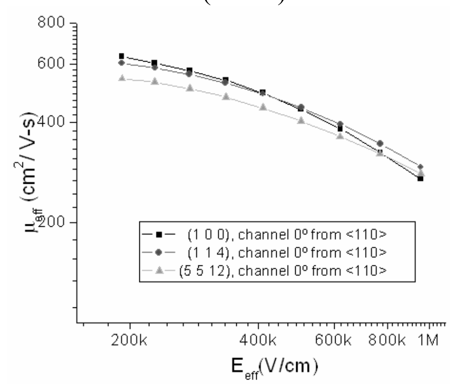

Fig.2. Electron mobility as a function of the crystal orientation for channels oriented at 0°.

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