Key words: ferroelectric, HfO$_2$, TiO$_2$, junctionless

Ferroelectric FETs (Fe-FETs) have been investigated for many years, because it may offer versatile opportunities in terms of low-power nonvolatile FETs. Recently, ferroelectric HfO$_2$ was found experimentally [1], and has been investigated for various promising applications, because HfO$_2$ is now dominantly used for advanced CMOS gate stacks. Substantial challenges of ferroelectric FETs for advanced device design are how to control the interface with semiconductors as well as the ferroelectric material properties. Furthermore, since the polarization charges are always too high for conventional semiconductor channels, it is required to reconsider the semiconductor material as well as appropriate FET structure. This paper discusses opportunities of ferroelectric FETs using doped HfO$_2$ on an oxide semiconductor channel, and demonstrates its nonvolatile FET performance.

We paid attention to ferroelectric N-doped HfO$_2$ [2], because very small N was needed to make HfO$_2$ ferroelectric and N may not degrade the interface as compared with metallic cation as the dopant. N-doped HfO$_2$ films were grown by rf-sputtering by introducing controlled amount of N$_2$ into Ar, flowed by PDA at 600°C. 40-nm-thick HfO$_2$ exhibited typical P-E characteristic. Although Si is practically the best material for the channel material, when a huge polarization charges (10~100 μC/cm$^2$) in common ferroelectric films, including HfO$_2$, are taken account, high permittivity channel materials would be better. Thus, high mobility (~10 cm$^2$/Vsec, k~100) TiO$_2$ grown by PLD [3] was employed as the channel material. Furthermore, since charge accumulation type FETs were considered to be inevitably affected by the interface quality, the junctionless type FET was designed.

Fig. 1 (a) shows a schematic view of 40-nm-thick 0.34% N-doped HfO$_2$ film with 10-nm-thick 0.2 wt.% Nb-doped TiO$_2$ as the n-type channel layer, and (b) shows the top view under the microscope. FET characteristics are shown in Fig. 2, in which (a) $I_{DS}$-$V_{DS}$ and (b) $I_{DS}$-$V_{GS}$ characteristics are shown. The saturation behavior is a little degraded in $I_{DS}$-$V_{DS}$, while the subthreshold characteristics show the counter-clockwise hysteresis and the surprisingly low off-leakage current. The hysteresis width is roughly 5 V in this case, because the coercive field of HfO$_2$ is rather large. This value is adjustable by changing HfO$_2$ thickness.

This work was supported by JST-CREST(JPMJCR14F2).

References  

Figure 1 Schematic view of Fe-FET with ferroelectric N-doped HfO$_2$ (40 nm) on Nb-doped TiO$_2$ (10 nm). This is the junctionless type FET. (b) Top view of the present FET. Electrode material is Al for source, drain and gate.

Figure 2 (a) $I_{DS}$-$V_{DS}$ and (b) $I_{DS}$-$V_{GS}$ characteristics in N-doped HfO$_2$ on Nb-doped TiO$_2$ channel. $V_n$ is not optimized in this device, but a very stable memory window is exhibited.