NON-VOLATILE n^+-TiO_2 CHANNEL FETs WITH FERROELECTRIC HfO_2

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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 600ºC. 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 $\mu C/cm^2$) 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. An appropriate electrode material selection in place of Al is needed to adjust V_{th}. Ferroelectric HfO_2 scalability and reliability have been already investigated in capacitors, and the remanent polarization gradually increased with the HfO_2 thickness decrease down to 5 nm. Furthermore, thin ferroelectric HfO_2 (~5 nm) had a higher cycling tolerance than thick (30 nm) one [4]. Therefore, both scalability and reliability in thin ferroelectric HfO_2 FETs are very promising for versatile applications of scaled devices as well as for back-end non-volatile switches.

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References [1] T. S. Boscke et al., APL 99, 102903 (2011). [2] L. Xu et al., APEX 9, 091501 (2016). [3] T. Yajima et al., Phys. Stat. Sol. A. 213, 2196 (2016). [4] X. Tian et al., IEDM (2017).

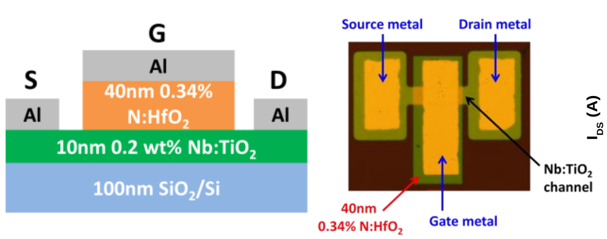

Figure 1 Schematic view of Fe-FET with ferroelectric N-doped HfO_2 (40 nm) on Nb-doped TiO_2 (10 nm). This is the junctionless type FET. (b) Top view of the present FET. Electrode material is Al for source, drain and gate.

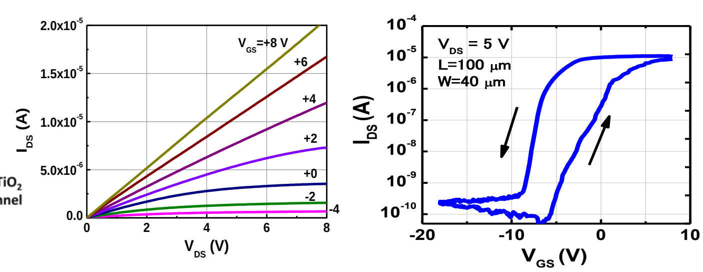

Figure 2 (a) I_{DS}-V_{DS} and (b) I_{DS}-V_{GS} characteristics in N-doped HfO_2 on Nb-doped TiO_2 channel. V_{th} is not optimized in this device, but a very stable memory window is exhibited.