Rare-earth based mixed oxide as high-k gate dielectrics for Ge MOSFET

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Germanium CMOS is considered to be a promising candidate for beyond scaling devices because of its inherent high bulk carrier mobility [1]. However, it is obvious that the interface layer control at dielectric/Ge is the most important issue in state-of-the-art Ge technology. Therefore, the following issues need to be addressed; what will be the best Ge intimate high-k material and how to control the interfacial layer (IL). Recently, rare-earth scandates ($ReScO_x$, Re being Y, La or a lanthanide) have drawn much attention as a promising high-k candidates particularly for Si devices, however, that with Ge has not yet been explored [2]. Here, we present the electrical characteristics of La-Sc and Y-Sc based mixed oxide directly deposited on (001) Ge.

The (001) oriented n-type Ge wafers (resistivity: 0.1-1.0 Ω-cm) were taken in this experiment. After repeating cyclic dip in (1%) HF solution followed by rinsing in de-ionized water, an *in-situ* high-vacuum (~10^{-9} Torr) anneal at 550°C was performed in MBE chamber for native oxide removal. Thereafter, a sequential multilayer stacked LaO/ScO or YO/ScO films were deposited on (001) Ge by e-beam evaporation from the corresponding oxide targets under background pressure of ~2×10^{-8}Torr at room temperature which finally will transform into $LaScO_x$ or $YScO_x$ after intermixing upon annealing treatment (T_{phy}:~8-9 nm, EOT:~2.5 to~3.25nm). The electrical characterization of MISCAPs with tungsten (W) gate-electrodes was measured using Agilent E-4980A precision LCR meter and 4156C.

The chemical composition and bonding configuration of the IL have been assessed by probing AR-XPS of La 3d, Sc 2p, Y 3d and Ge 3d core level spectra as shown in Fig. 1. Although, a mixture of several Ge sub-stoichiometric oxides, GeO_x ($1<x<2$) are identified without any detection of dioxide state (Ge^{4+}) which thus indicates growth of an IL, however, the amount of IL was found to be suppressed effectively with $YScO_x$ over that with $LaScO_x$; rather growth of a Y-Sc-Germanate like IL is expected in combination with Ge^{3+} for $YScO_x$. Eventually, $LaScO_x$ devices demonstrate a shift in flat-band voltage,V_{fb} towards even less positive values while it intrudes even larger hysteresis (>400mV) with ScO% more or less than 50% (see Fig. 2). On the contrary, $YScO_x$ samples as shown in Fig. 3 exhibit rather drastic improved hysteresis (~50mV) which is anticipated as a result of prominent Y-Sc-germanate like IL growth compare to GeO_x-based IL while the observed larger hysteresis in case of $LaScO_x$ is mostly due to the formation of a GeO_x-based IL in consequence of more dominant intermixing or Ge out-diffusion into La-Sc oxide complex. Nevertheless, the growth of IL can be controlled via Si-passivation; consequently a drastic improvement in electrical performance can be achieved with $LaScO_x$ (see Fig. 4). Indeed, an improved leakage current behavior has been observed with $YScO_x$ over $LaScO_x$ (see Fig. 5) which in term suggests that Y-Sc oxide complex will be a promising Ge intimate high-k insulator.

In summary, La-Sc and Y-Sc based mixed oxide as high-k gate insulator for Ge MOSFET have been evaluated through physical and electrical characterizations.

References: [1] C. O. Chui *et al.*, *IEE Electron Dev. Lett.*, **23**, 473(2002). [2] M.K. Bera *et al.*, to be published in *ECS Trans.* (2009).

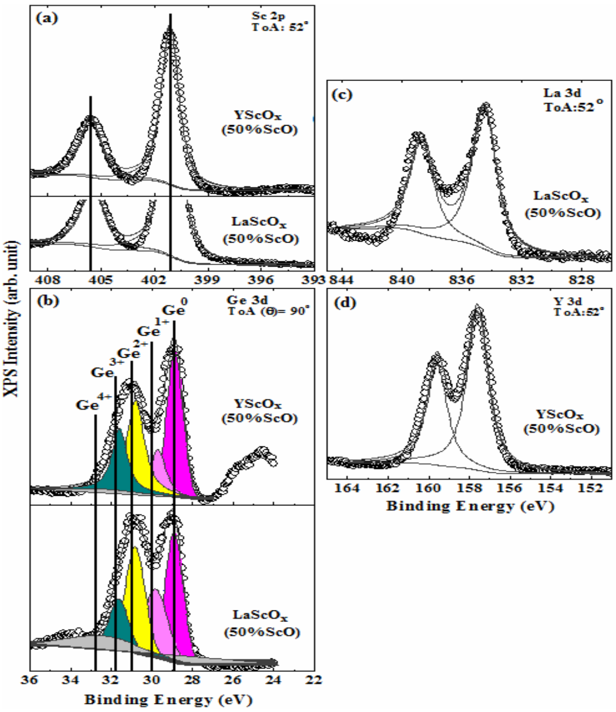

Fig. 1: XPS core-level spectra of (a) Sc 2p, (b) Ge 3d, (c) La3d, and (d) Y 3d for $LaScO_x$ and $YScO_x$ directly deposited on (001) Ge.

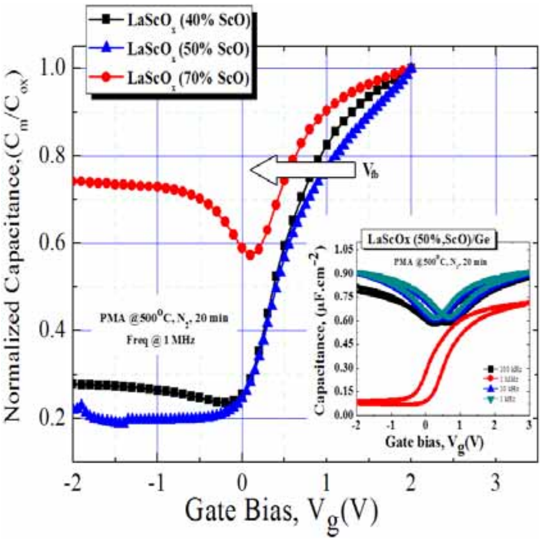

Fig. 2: 1 MHz C-V characteristics of various ScO concentrated $LaScO_x$. Inset shows the bi-directional C-V sweeps of $LaScO_x$ having 50% ScO concentration showing large hysteresis.

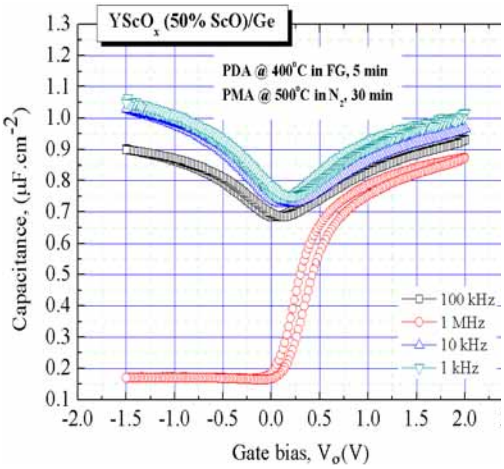

Fig. 3: Frequency dispersion in bi-directional C-V sweeps of $YScO_x$ (50% ScO) showing small hysteresis.

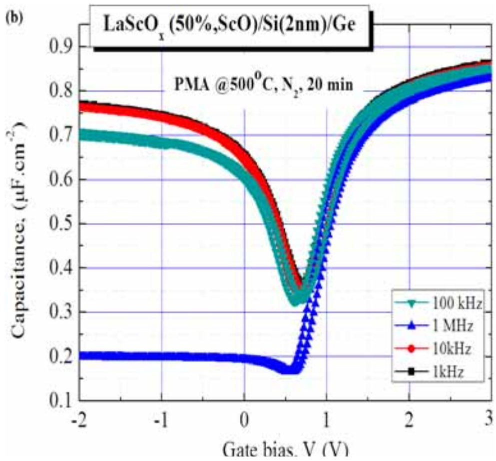

Fig. 4: Frequency dispersion in bi-directional C-V sweeps of $LaScO_x$ (50% ScO) deposited on Si-passivated Ge.

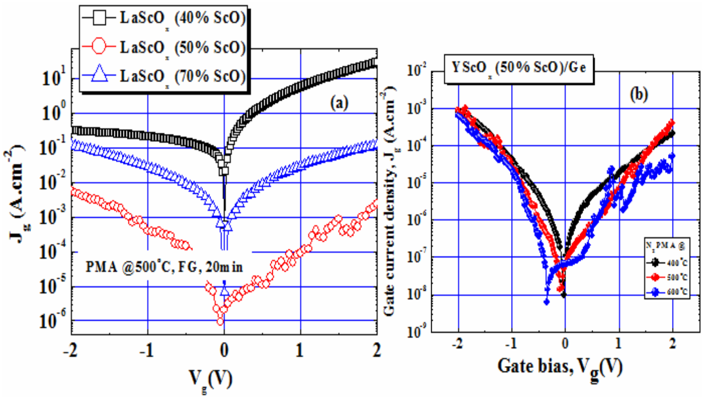

Fig. 5: A comparison of J-V characteristics of (a) various ScO concentrated $LaScO_x$ and (b) annealing temperature dependence in case of $YScO_x$.