Insulators for 2D Nanoelectronics

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The selection of suitable insulators for 2D FETs represents an enormous challenge as scaling towards sub-10nm channel lengths is only possible with gate insulators scalable down to sub-1nm equivalent oxide thicknesses (EOT). In order to achieve competitive device performance, these insulators need to meet stringent requirements regarding (i) low gate leakage currents, (ii) low density of interface traps, (iii) low density of border insulator traps and (iv) high dielectric strength. Thus, careful selection requires the analysis of available insulators with respect to these major criteria. In addition, technological requirements such as the possibility for top gate integration and for threshold voltage tuning to achieve symmetric n- and p-FETs for CMOS should be taken into account.

The insulators for 2D electronic devices typically are amorphous 3D oxides known from Si technologies (SiO_2, HfO_2, Al_2O_3), but native 2D oxides (MO_3, WO_3 and Bi_2SeO_5), layered 2D crystals (hBN, mica) and ionic 3D crystals (CaF_2 and other fluorides) have been also used. 3D oxides form poor quality interfaces with 2D semiconductors (Fig.1a) and contain border traps which severely interfere with stable device operation [1]. The latter also applies to most native oxides, which are non-stoichiometric [2] and have a limited dielectric stability. hBN, on the other hand, forms excellent van der Waals interfaces with 2D semiconductors (Fig.1b), but has mediocre dielectric properties (E_G = 6eV, $\varepsilon < 5$) which result in excessive leakage currents for sub-1nm EOT [3]. The potential of other 2D insulators (e.g. mica) is currently unclear, in part due to the absence of scalable growth techniques.

As a possible solution to the problem, we will discuss 3D ionic crystals like CaF_2 (E_G=12.1eV, ε=8.43) [4] which form well-defined interfaces (Fig.1c) and exhibit low gate leakage currents (Fig.1d). Recently, excellent performance (SS=90mV/dec, $I_{on}/I_{off}=10^7$) of MoS_2 FETs with just 2nm thick CaF_2 (0.9nm EOT) has been achieved. Apart from fluorides, native oxide Bi_2SeO_5 (E_G=3.9eV, ε=21) [5] is also promising as it already offers top-gate integration for FETs, while forming atomically sharp interface with its semiconductor Bi_2O_2Se. However, the narrow bandgap of this material may present a challenge for scaling, while its dielectric strength and border trap distributions have to be examined as well.

In summary, we stipulate that amorphous 3D oxides are not suitable for integration into 2D FETs. Thus, an intensive search of beyond-hBN layered insulators and further development of 2D devices with epitaxial fluorides and native oxides appears promising.

References

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Figures

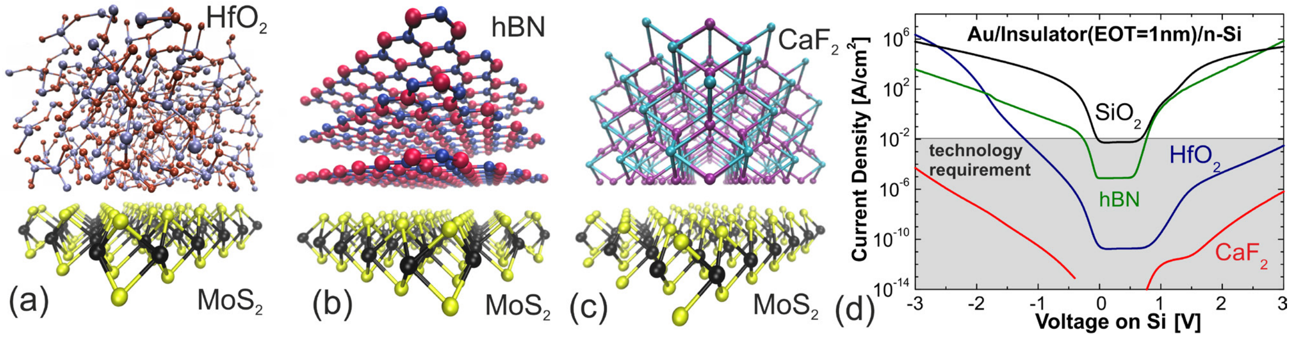

Figure 1: Schematic structure of MoS_2/HfO_2 (a), MoS_2/hBN (b) and MoS_2/CaF_2 (c) interfaces. (d) Theoretical leakage currents through these insulators for EOT=1nm.