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Invited Paper

Topics: Organic Materials and Devices, and Oxides and Dielectrics

Dielectric and Semiconductor Design Strategies for Low Power Hybrid Electronics

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Because of the need to power organic and hybrid transistors-based electronic components with batteries supplying <10 V, it is necessary to increase gate capacitances of the transistors and also minimize leakage current either because of tunneling or through imperfections in the dielectric films, while maintaining sufficient switching speed. This talk will focus on strategies aimed at these goals

Self-assembled monolayers and organic semiconductors on thin silica dielectrics. We show for the first time that the internal dipole moment of a self-assembled monolayer can create a local electric field that inhibits leakage currents in organic TFTs. We explored minimally thick (10 nm) silica on both n and p-doped silicon wafer gate substrates as models for thin, printed dielectrics that would be expected to be more defective than the traditional higher-quality thermally-deposited dielectrics. The partially fluorinated organosilane 1H,1H,2H,2H-perfluoro-octyltriethoxysilane (FOTS) monolayer material includes a dipole moment on the order of 2 Debye associated with the bond between the fluorinated and nonfluorinated segments. The dipole is oriented so that its associated electric field opposes the field applied to the TFT when the drain lead is powered and the gate voltage is set to "off" (near zero or negative for an n-channel semiconductor.

We use a highly self-assembled naphthalenetetracarboxylic diimide (NTCDI) semiconductor whose conjugated core is essentially transparent to visible light. The dipole field provided a two-order-of-magnitude decrease in gate leakage current and subthreshold leakage. Comparison with the nonfluorinated octyltriethoxysilane (OTS) established that the internal dipole was significantly responsible for the effect, as the silane-surface dipole differed on n- and p-silicon substrates, but the FOTS was equally effective on both. Our results highlight the potential of dipolar SAMs as performance-enhancing layers for marginal quality dielectrics, broadening the material spectrum for low power, ultrathin organic electronics. We also examine the contributions that side chains on the NTCDI molecules can make to the dielectric behavior, further minimizing the needed oxide thickness and also possibly maximizing the effective charge carrier mobility in the lateral direction.

Ionically polarizable aluminas with zinc tin oxide semiconductor. We have recently reported transistors using mixed zinc oxide semiconductors and alumina dielectrics where both are deposited using sol-gel techniques. Zinc tin oxide has been particularly useful, providing electron mobilities on the order of 20 cm^2/Vs. It also forms a well-performing interface with high-capacitance alumina dielectrics, where the polarization of included alkali metal ions adds up to an order of magnitude to the dielectric constant compared to ordinary alumina. Lithium, sodium, and potassium ions can all be included, and coating methods include dip and spin coating, and presumably spraying and printing as well. These zinc tin oxide (ZTO) FETs can output hundreds of microamperes with an operational voltage of 2V. Even organic transistors using semiconductors such as pentacene or the NTCDI-type molecules mentioned above can exploit the high dielectric constant. While we originally thought that the high dielectric constant came from polarization perpendicular to channels associated with a layered "beta-alumina" crystal structure, we

now find that the aluminas are largely amorphous and that ions can travel through extended spaces in the amorphous structure.

Transistors that we make using these oxides exhibit excellent saturation behavior and usable on/off ratios. Leakage currents from the ion-included aluminas are only an order of magnitude higher than those of nonionic sol-gel alumina dielectric. The hysteresis observed on cycling the drain voltage to be minimal. Root mean square roughnesses of the ion-included aluminas are similar to those of neutral alumina. High capacitance is maintained in the dielectric layers even when they are on the order of 100 nm thick, encouraging for print applications.

To further the use of these kinds of devices where transparency is an important consideration, we have extended our materials set to include pyromellitic (benzenetetracarboxylic) diimide derivatives. These semiconductors, which can be in the form of polymers or small molecules, have even greater transmission windows than do the NTCDIs, and are even more likely to function as bifunctional semiconductor and dielectric materials in field effect transistor geometries. We have optimized the fluorinated side chain length of these compounds for the less extensively conjugated semiconductor molecules, and also developed new substitution chemistry for the benzene rings. Unusually high electron mobilities are obtained considering the atypically low degree of conjugation.