

Molecules as Segmented Storage Elements in Floating Gate Memories

Sarah Paydavosi, Hassen Abdu and Vladimir Bulovic

Laboratory of Organic Optics and Electronics

Massachusetts Institute of Technology, Cambridge, MA 02139

Our work demonstrates the first step towards a possible approach to miniaturization of non-volatile memory by using molecules as segmented charge storage elements in the floating gate flash memory technology. In the operation of the demonstrated structures we rely on the innate strengths of the van-der-Waal-bonded organic thin film technology, namely strong charge localization on individual molecules and concomitant low charge mobility in organic thin films.

As demands for high storage density, high chip memory capacity, and decreasing process costs continue, conventional flash memory technology appears to be reaching fundamental scaling limits. To surmount the challenge of scaling-down of floating-gate nonvolatile memory cells in advanced nodes beyond 45 nm, segmented floating gate memories are presently considered.

In recent demonstrations of nano-segmented memories the polysilicon floating gate was replaced with a sectioned gate consisting of multiple nanoparticle quantum dots (QDs), so that charge storage is distributed over multiple QD sites, making the device more immune to inadvertent defects in thin tunneling oxides. As commercial flash systems require less than 5% variation in charge storage, less than 5% variations in number of QDs in the floating gate is also required. From the empirical data on QD packing, we simulated the variation in number of QDs versus area for different QD arrangements including, unordered QD monolayers, perfect hexagonally close-packed monolayers with random orientation and position, and perfect hexagonally close-packed monolayers with defined orientation but random positions. Based on this analysis we conclude that the 45nm technology node would require use of hexagonally packed ordered QD monolayers with a QD-to-QD center distance spacing of 4nm or less, which could result in significant QD-to-QD charge tunneling, obviating the intended benefit of nanostructuring the gate electrode to preserve charge on individual QDs and decrease lateral discharge paths. In light of these results, in the present work we suggest and demonstrate that molecules can serve as segments of a nano-segmented programmable floating gate, Organic dye molecules that are on the order of 1nm in size represent a uniform set of identical nanostructured charge storage elements, while lateral mobility of many molecular thin films is sufficiently low to inhibit significant charge transport.

To demonstrate the viability of molecular thin films as charge-retaining floating gates, we compared the memory behavior of a variety of molecular thin films in a capacitive floating gate geometry and identify the molecular thin film characteristics best suitable for design of floating gate memory structures. We made a set of memory structures using organic thin films of 3,4,9,10- perylenetetracarboxylic bis-benzimidazole (PTCBI), 3,4,9,10-perylenetetracarboxylic dianhydride (PTCDA), tris-(8-hydroxyquinoline) aluminum (Alq3), and fullerene (C₆₀) as the floating gate in structures that utilized 4.8nm thermal SiO₂ layer on top of a p-type Si substrate. The molecular organic layers were thermally evaporated at a base pressure of $<6 \times 10^{-7}$ Torr to form 10

nm thick charge storage films. A 15 nm thick Al₂O₃ capping layer was sputtered on top of the organic layer followed by Al deposition as a gate electrode. The initial results show device durability over 10⁵ program-erase cycles, with hysteresis window of up to 3.3 V for program/erase conditions of +8V/-8V, with voltage held for 20sec at each bias. From the *C-V* shift we estimate the stored charge density of 5×10¹² cm⁻² for these devices, which is comparable to the best storage densities obtained in the state-of-the-art devices.