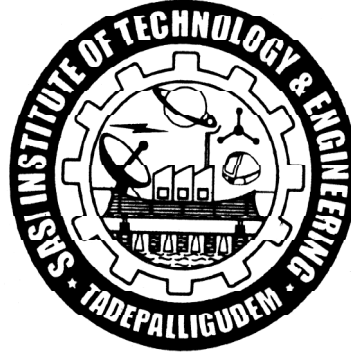


SASI INSTITUTE OF TECHNOLOGY & ENGINEERING



PAPER PRESENTATION

ON

**“ Carbon Nanotube - Based
Nonvolatile
Random Access Memory ”**

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Carbon Nanotube- Based Nonvolatile “Random Access Memory”

Abstract

Carbon nanotubes exhibit outstanding structural, mechanical and electronic properties, which make them ideal wires for molecular electronics. Nanotechnology proposes using nano-scale carbon structures as the basis for a memory device. Recent developments in nanodevices presented a new approach for a highly integrated, ultrafast, nonvolatile Random Access Memory (RAM) based on carbon nanotubes.

A single-wall carbon nanotube would contain a charged buckyball. That buckyball will stick tightly to one end of the tube or the other. The bit value of the device is assigned depending on which side of the tube the ball is. The result is a high-speed, non-volatile bit of memory. A number of schemes have been proposed for the interconnection of these devices and

examine some of the known electrical issues.

This paper consists of the basic issues involved in building a RAM out of carbon nano-structures. An attempt has been made to simulate the various problems and challenges to frame the carbon nanotube memory devices.

Introduction

If the DRAM industry is to continue with its exponential rate of density improvement, it seems likely that there will need to be a radical change in the construction of memory devices at some point. Certainly quantum-dot devices have possibilities in this role. A different possibility is in the construction of a nanometer-sized memory device based on the self-assembly of buckyballs inside of carbon nanotubes. This “bucky shuttle” memory offers nonvolatility and

terahertz switching speeds. Also, each bit could require as little as two square nanometers.

The possibilities of such SWNT in RAM are quite interesting. Current dynamic RAM requires both a transistor & capacitor (the transistor stores or releases a charge from the capacitor). And it's dynamic because the capacitor, which loses charge very quickly, needs to be refreshed constantly.

The Carbon nanotubes are nonvolatile—that is, once it's in an “on” or “off” state, it stays there, so there's no refreshing involved (saving processing time as well as work).

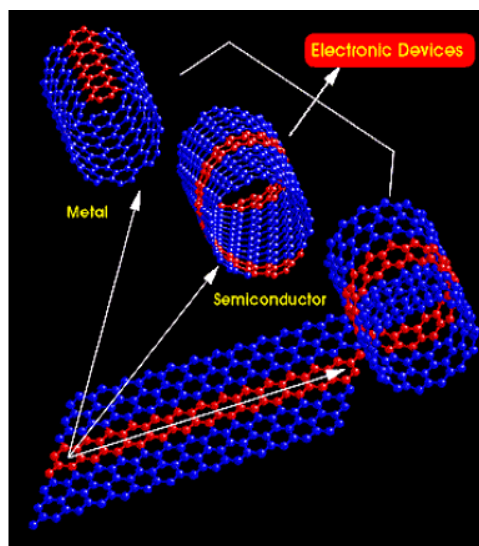
The angle that the nanotubes bend when “on” is LESS than the buckling angle for Carbon nanotubes.

With current Static RAM, 4-6 transistors are needed. 2 inverters (each with 2 transistors) with the input of one going to the output of the other store a bit, and 2 more for the read & write lines. Whereas a single nanotube can have several junctions, each storing a bit. The switching time (determined by the time to move the upper nanotube between the bitable states) is 100Ghz (MUCH faster than current processors). Also the storage

capacity is incredible—116 gigs per square cm.

Fullerene nanotubes

Carbon atoms can form a number of very different structures, two of the better known are diamond and graphite. A new carbon structure, the buckyball, was discovered in 1985. Soon after, the nanotube was discovered. These carbon structures, collectively known as fullerenes, have been of great interest to the physics and chemistry communities.



Graphite consists of sheets of carbon atoms in a hexagonal arrangement (see Figure 1). The sheets are very loosely connected to each other. Taking a

single sheet of graphite, cutting a long narrow strip and rolling it into a long, narrow tube would be a nanotube. The ends of the tubes usually form caps, as the dangling atoms will be receptive to forming bonds with their neighbours. The resulting structure is shown in (Figure 2). The electrical properties of the newly created nanotube depend upon the exact angle at which the graphite was cut. A cut along one of the edges of the hexagons would result in a conductive “armchair” nanotube. Other angles would result in semi-conductors and even insulators. This *chiral angle* can range from 0° and 30° .

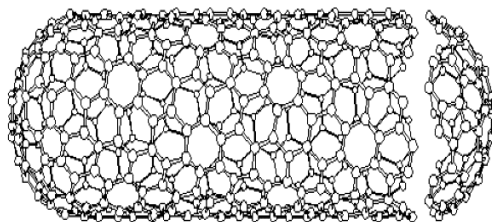


Figure 2 A carbon nanotube

A buckyball can be thought of as the smallest of the nanotubes. It is simply the connection of the two caps with no “tube” in between, and consists of exactly 60 carbon atoms (see Figure 3). Its combination of hexagons and pentagons is exactly the same as that found on a soccer ball. Generally very short nanotubes with

70, or even 80 atoms are sometimes also called buckyballs.

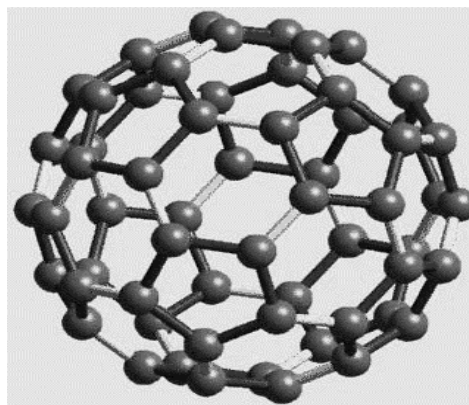


Figure 3 A buckyball

The Nanomemory Device

The proposed nanomemory device (NMD) consists of two parts: the “capsule” which holds the much smaller, charged “shuttle.” (Figure 4) shows an example where the capsule is a C_{240} nanotube while the shuttle is a buckyball. The buckyball contains a potassium ion (K^+), which gives the shuttle its charge. The outer dimensions of this capsule would be about 1.4nm in diameter and about 2.0nm in length. This K^+ inside of a C_{60} inside of a C_{240} ($K^+@C_{60}@C_{240}$) structure is the smallest and simplest device that is considered. However other options such as longer capsules, which uses other nanotubes as shuttles, as well as having many charged shuttles inside of each NMD are promising.

The state of the memory device is determined by the location of the shuttle: if it is on one side of the capsule, it is treated as a '1'; on the other it is treated as a '0'. The Vander Waals forces between the tube and the shuttle will tightly bind the shuttle to one end of the tube or the other. There is an unstable equilibrium point when the shuttle is in the exact middle of the capsule, but the proposed scheme for writing to the device would prevent the shuttle from ever coming to rest there.

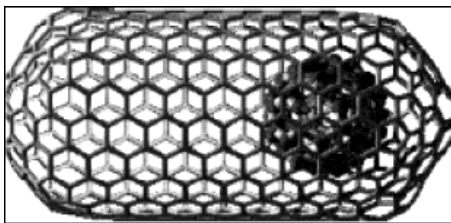


Figure 4 An example nanomemory device

Writing to the NMD

The potential energy of the shuttle at various locations in the NMD is shown in (figure 5). The solid line indicates the potential energy curve when no electric field is applied. The two potential energy wells are found when the shuttle is on one side of the capsule or the other. These wells keep

the shuttle bound to either side of the capsule. The other two lines display the potential energy when a two-volt potential difference is applied. When such a voltage is applied there exists only one local minimum, and the shuttle will move to that side of the tube. It is with this two-volt potential difference that provides means to write to the NMD. In general the amount of voltage, which needs to be applied, depends upon the length of the capsule. A field of 0.1 volts/c is sufficient to move the shuttle from one side of the tube to the other.

One important issue is how long it takes to perform a write to the NMD. Because of the bouncing effect observable in (Figure 6) it is necessary to wait for the buckyball to come to a stop. Generally the time to settle will be about 20 picoseconds.

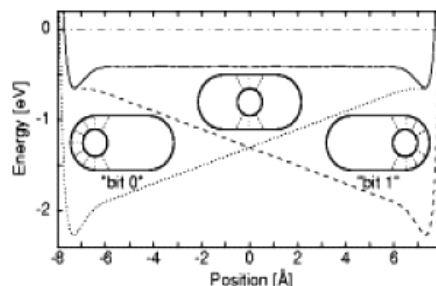


Figure 5 Potential energy of the shuttle at different locations in the capsule. The solid line is when no electric field is applied. The dashed lines are the potential energy when the two-volt potential difference is applied.

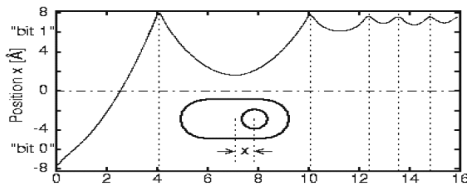


Figure 6 Location vs. time of the shuttle as a write is preformed.

Time is in picoseconds.

Reading from the NMD

Writing to the nanomemory devices is the easy part; reading from them is much more challenging. Somehow the state of the device must be sensed. Numbers of ways have been proposed to perform a read.

The first requires three wires to be connected to the capsule: one on each end, and one in the middle. The position of the buckyball is detected by examining the resistance between the middle wire of the nanotube and the ends. A lower resistance will be found on the end that has the shuttle. This three-wire solution has a number of problems, not the least of which is that making a connection to the middle of a nanotube seems difficult. However, a long capsule and shuttle would perhaps make this solution viable.

A device without the middle wire would be easier to fabricate. The notion of a destructive read could be

applied here. A read would then be performed in the same way as a write. During that write some current will flow if the shuttle moves from one side of the nanotube to the other. The total current that will flow is limited by the amount of charge held in the shuttles. It is this type of a read that makes a necessity to use many shuttles in our capsule to attempt to increase the amount of the current flow. Neither of these reading schemes is particularly satisfactory.

From NMD to RAM

Once the memory device is fabricated it will still be a challenge to integrate the devices into a large RAM cell. The two possible implementations are "metal-wired" and "nano-wired". The metal-wired approach is the most viable implementation. However, it is equally useful as a stepping-stone on the path to the nano-wired device, which offers tremendous density improvements.

Metal-wired

The easiest device to fabricate would replace the traditional DRAM capacitor/transistor memory cell with a large number of nanomemory devices. Current VLSI fabrication techniques

could be used, but with the addition of a layer of nano-devices. A “forest” of nanotubes has been already built, and a similar technique could be used to create a forest of memory devices between two conducting layers. (Figure 7a) is a representation of a 4-bit nanomemory device. (Figure 7b) shows a more detailed view of a single bit. A number of nanomemory devices are used to make up a single bit of memory. The number of devices per bit will depend upon the minimum line size of the lithography process used. With a 70nm wire width there could be nearly 1,000 nanomemory devices per bit.

Considering how a write to the memory device in (Figure 7) will work: Nearly a voltage differential of 2.0 volts will move the shuttles from one side of the capsule to the other. In order to write a ‘0’ to bit three, a +1.0 volt potential is applied to wire B and a -1.0 volt potential to wire D. If all the other wires are held at ground, only at the addressed bit will there be a strong enough electrical field to the shuttles. A ‘1’ is written by reversing the voltages. Writing to an entire row (or column) would be a two-stage process

as the 1’s and the 0’s would have to be written at different times.

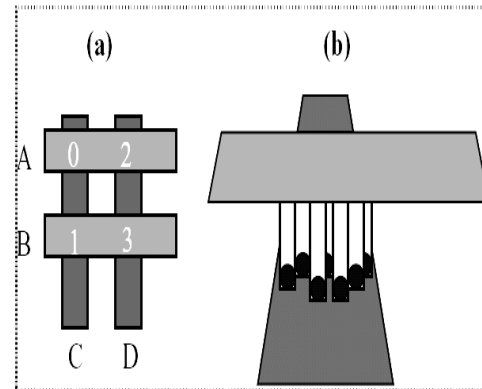


Figure 7 (a) 4-bit nanomemory device with wires A, B, C, and D. (b) a single-bit using forest of NMDs.

Considering a destructive read with a forest of nanotubes: Forest of nanotubes move a large number of charged ions. The data in the process of doing the read will get destroyed if those ions move. However, it can be written back later, much as it is handled in a traditional DRAM. This metal-wired carbon nanomemory device has a number of useful features. It is non-volatile, the device itself switches very quickly, and it would seem to be just as buildable using 70nm lithography as it is using 350nm lithography.

Nano-wired

In this scheme, the memory array is made entirely out of nanomemory devices and carbon nanowires. The metal wires are replaced by conducting nanotubes. Each bit of memory uses only a single NMD. The logic, sense-amps and pads are made using traditional devices. It is similar to the metal-wired proposal. Nano-wires allow for *very* high densities, with each bit fitting in about two square nanometers. Laying out this network of carbon requires self-assembly techniques well beyond anything we can do today.

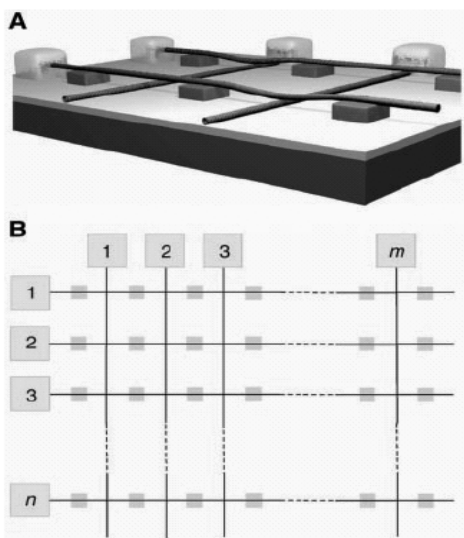


Figure. 8. Suspended nanotube device architecture. (A) Three-dimensional view of a suspended crossbar array showing four junctions with two elements in the ON (contact) state and two elements in the OFF (separated) state. The substrate consists of a conducting layer [e.g., highly doped silicon (dark gray)] that terminates in a thin dielectric layer [e.g., SiO₂ (light gray)]. The lower nanotubes are supported directly on the dielectric film, whereas the upper nanotubes are suspended by periodic inorganic or organic supports (gray blocks). Each nanotube is contacted by a metal electrode (yellow blocks). (B) Top view of an n by m device array. The nanotubes in this view are represented by black crossing lines, and the support blocks for the suspended SWNTs are indicated by light gray squares. The electrodes used to address the nanotubes are indicated by yellow squares.

conclusion

The proposed nanomemory device is one candidate for carrying memory devices beyond the limits of current DRAM technology. It has three important characteristics: it is small, non-volatile, and fast. At this point the carbon nanomemory has been simulated and buckyballs inside of nanotubes have been created, but a working memory device does not exist. Building it will be a challenge, but self-assembling carbon nanotechnology is an active research area with continuous and promising advances.

References

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