CAN ET PULL US UPWARD?

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ABSTRACT
The doldrums seem to linger on endlessly. Yes, there are bright spots to be sure. But there are also black holes that siphon off energy and extinguish the embers. Can Emerging Technologies (ET) help pull us out of the hole and launch us back to more a stellar orbit?

Perhaps! This paper will shine light on ET and help demystify some of the elements. We will take a broad-brush sweep to visualize emerging areas of new materials, devices and systems. We'll delve into issues and analyze some of the potentially important areas that can catalyze truly new businesses. We seek some answers.

Is nanotechnology really new or a hyped up version of chemistry 101? What about MEMS? Has a single company really sold 100-million MEMS chips? And if this is true, is MEMS the next big thing in the world of tiny technology? Is the cinema going "filmless" as digital finally moves into the movie business? Today, you can see a digital movie in any one of dozens of theaters, but how does it work and what does it foretell about future home entertainment? Will Blockbuster rent videos through the Internet to play in your MOEMS home theater or on your PDA? Did you download your favorite author's e-book for the trip? You can do it today.

We will survey the most unusual, fascinating and far-reaching members of the ET family and then predict the future. So come join us to find out why the best is yet to come and the limit is your imagination.

Keywords: MOEMS, MEMS, Nanotechnology, telecom, Wi-Fi

INTRODUCTION
There are two sides to emerging technology, the basic science part and the rendered products. First we'll scan the leading edge technologies and then take a look at the fascinating new products that will help boost our economies and help to make life better, or at least, more interesting.

Here's our ET list for 2003. MEMS is still going strong. MicroElectroMechanical Systems are doing well. The technology is moving steadily ahead and will not display the "Roman Candle" effect seen in some other areas. MEMS is strong, not because it's climbing to high summits, but because it is moving into so many fields to some day become all-pervasive like computer chips. Next of kin, MOEMS, or optical-MEMS, is also advancing at a healthy pace. The addition of optics lets the technology solve photonic switching problems but also produce new displays. Let's also add another close kin, MicroStructure Technology, or MST. Let's not confuse MST and MEMS - they are not synonyms. MST will help telecom products become even smaller, more powerful and energy conserving, as we'll see in the products section. Have we missed any fundamental newer technologies? All right, we can add Nanotechnology to the short list and try and figure out what it really is, first.

What about the end products, what is significant enough to help turn the wheels of the world economy a little faster? The center is telecom, the same winner as last year. But we can get more specific. Mobile telecom is the central hub with many spokes. And mobile telecom is a lot more than a cell phone. So let's examine the quadrangle of technologies first.

MEMS
We can look at MEMS as an IC with "muscle and senses". Some devices can move and manipulate materials and the ink jet printer chip is a good example, albeit the simplest one. More complex devices can pump and control biological materials offering future breakthroughs in medicine. But the largest, and still the most important area is sensors, especially motion detectors. Here, signals are produced when the device changes position that, in turn, causes its electromechanical components to move. Accelerometers remain the "workhorse" in the MEMS sensor arena, but gyroscopes are advancing and are now commercially available. Later, we'll take a look at applications that are spawning new products. But is MEMS still just a lab item? Leading MEMS sensor producer, Analog Devices, Inc., shipped its 100-millionth accelerometer in 2002, and also announced the first commercial MEMS gyroscope. Figure 1 shows an ADI 2-axis accelerometer chip and Figure 2 shows the gyroscope. Now, we'll move to MST to find out where it fits and how it is different.

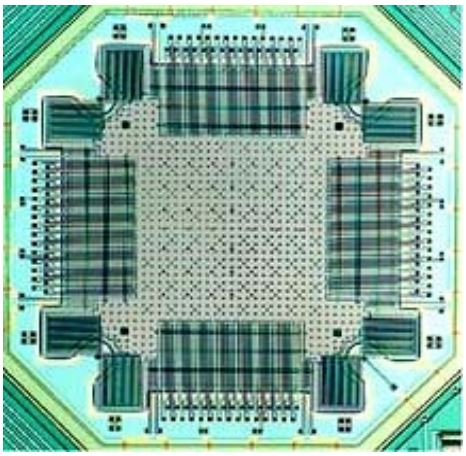
Figure 1 – Accelerometer - ADI

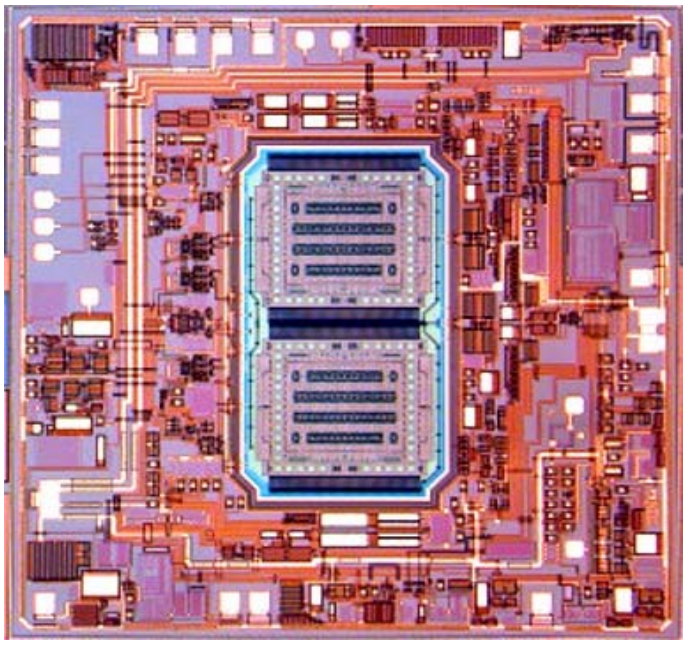

Figure 2 – Gyroscope - ADI

MST

MST is often thought to be the European term for MEMS, but there is a very important difference, at least in the definition that will be used here. MST, although the fabrication methods can be similar to MEMS, does not have any moving parts. What is more, MST does not move material. The simplest MEMS devices, according to the definition from Sandia National Laboratories, do not have moving parts, but the device must move material. The MEMS ink jet chip that uses thermal heaters to propel fluid, is a good example. But MST can produce a stationary coil. Nothing moves, except electrons, they we won't include as material. MST can also use the LIGA process (Lithography, Galvanoformung, Abformung) to make all-metal parts instead of modified semiconductor methods used to make most of the MEMS products. LIGA can be viewed as a micro-casting process that uses very precise electroforming so well suited for making rf components, especially coils.

MicroStructure Technology is being directed toward the radio frequency telecom product area, although it is often lumped into RF-MEMS. The coils, capacitors, resonators, isolators, fixed filters and other new rf components, are moving to MST. The technology that employs precision microlithography is able to produce very tiny and precise components that are especially well suited for hand-held communicators. Filters and other components with inductors are expected to move to MST and will not only reduce size, but also economize on power consumption. The hold-up has been cost, but the excellent scalability of MST should overcome this concern. It should be noted that there are some rf devices that come under the MEMS definition, and not MST. These are the tunable systems that have moving parts, typically plates that make up variable capacitors. Figure 3 shows an rf MST filter designed by Nokia.

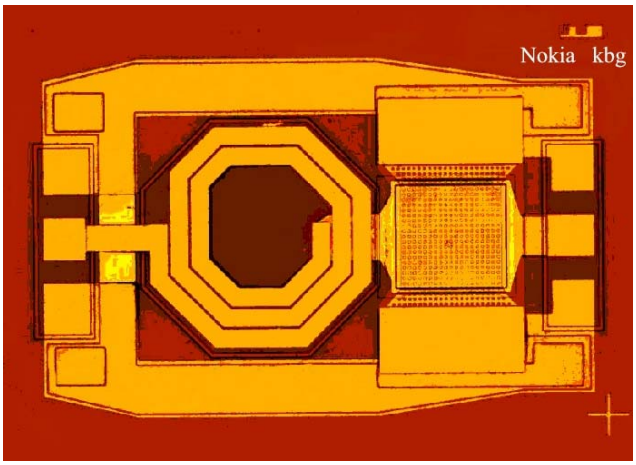

Figure 3 – NST rf Filter – Nokia Res.

Now we're ready to add light to MEMS and build the ultimate microchip, the Micro-Opto-Electro-Mechanical System (MOEMS). These devices can bring together the important fields of science and engineering and will eventually affect all of them. MOEMS is the convergence of electronics, mechanics, physics, optics, semiconductors, chemistry, biology and just about anything else you care to add. The most popular examples have been the light control chips you may have seen depicted as tilting and rotating mirrors. The mirror design remains popular, but other technologies, like fluid bubble jet switches, are also viable. But where will we use all of these switches? The Internet has not found it necessary to adopt the all-optical switch and router scheme and there is no longer a clear plan to do so. How about displays? What about entertainment? Consider how much visual information that the average person uses every day. Also consider how much of this is really entertainment. We'll look at end products later. Figure 4 shows a montage of MOEMS devices.

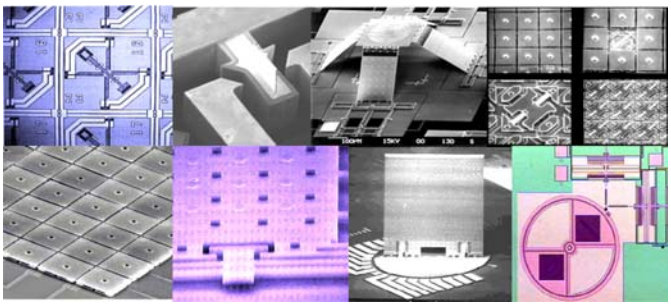

Figure 4 – MOEMS

Ready or not, here comes Nanotechnology. But what is it? Michael Crighton warns us of its dangers in his fictional book, "Prey". Forbes magazine warns of the Nano Pretenders, companies in Nano-name only that could help convert your funds into a nano-sized account. But the US government is investing nearly a billion dollars to jump-start the field, so we had better take nanotech seriously. The nanotech definition seems to fly around like the nanobots in "Prey", so let's try and pin it down. Nanotechnology is the production, examination, manipulation, transformation, and

control of matter, energy, and information at the nanometer-scale (1-100 nm) using precise individual atom processes instead of traditional bulk reactions (e.g.; chemistry). The key is the atom-by-atom approach as compared to less precise and controlled processes of just about every other technology. The nanotech principle can be credited to Nobel laureate Dr. Richard Feynman who looked 40 years ahead and predicted that products would be built one molecule or one atom at a time by the year 2000. His 1959 lecture, "There's Plenty of Room at The Bottom", gave birth to the nanotech concept. Feynman remarked, "What would happen if we could arrange the atoms one by one the way we want them…" Later, K. Eric Drexler, continued on the atomic-level theme in "Engines of Creation" (1986) where he suggested that nano-assemblers could build nano-structures. His solution to scaling up was to have the assemblers build more assemblers, a real stretch. Finally, in 1990, IBM was able to do atom-by-atom assembly with their atomic force microscope (AFM). Some mark the beginning of nanotechnology when IBM wrote "IBM" using 35 argon atoms placed on nickel shown in Figure 5.

Figure 5 – Nano Writing – IBM Corp.

So, if we accept the "one-atom-at-a-time" definition, the real issue is productivity. We would need to assemble millions of atoms per second to be able to ship in your lifetime. Sure, we can have the universal assembler make copies of itself – just replicate like real life forms! Some, including this writer, feel that such an idea is an illusion that should stay in the realm of science fiction with Crighton's replicating nanobots. While the idea of man-made self-replicating assemblers is not impossible, the concept is far from practical if you don't cheat. The simplest "live" assemblers are made up of millions of atoms. IBM took an entire day just to place the 35 atoms. Do the math! What about alternatives to robots that build robots?

Fortunately, there is a well-established atom/molecule based science called chemistry. Chemists have been doing atomic assembly for a few centuries. Granted, chemical syntheses is not as precise as atom-manipulation molecule construction, but the imprecise chemists have cataloged over 10 million unique molecular structures and synthesized most of them. Chemical plants produce millions of tons of materials each year and most of the molecules have very precise structures. Water is H_2O, not H_XO, and the digit is exactly "2", not some average. Biosystems are even better at making very large and very exact molecules. So when we talk about commercial Nanotech, we're going to have to use micro-mechanical engineering, chemistry, biology or all of them. But although the results will be nano-scale, the process may not fit the nanotechnology definition.

Several dozen nanopowders have already been produced and are commercially available. More complex, and extremely popular nanocarbon tubes (CNT) have also been constructed, but not with assemblers. Chemical-based routes are now being used to make CNTs in volume and the products can even be purchased. Figure 6 shows the CNT structure. Each connection point is a carbon atom. The CNTs have been generating considerable excitement, especially in the electronic device field. We can expect Nanotechnology to slowly evolve into a very big future. The nano-materials are moving relatively quickly into products, but devices may also advance faster than the experts predict with so many companies, institutes and universities working in the area. Now let's move to the new product area and see where the ETs are being used.

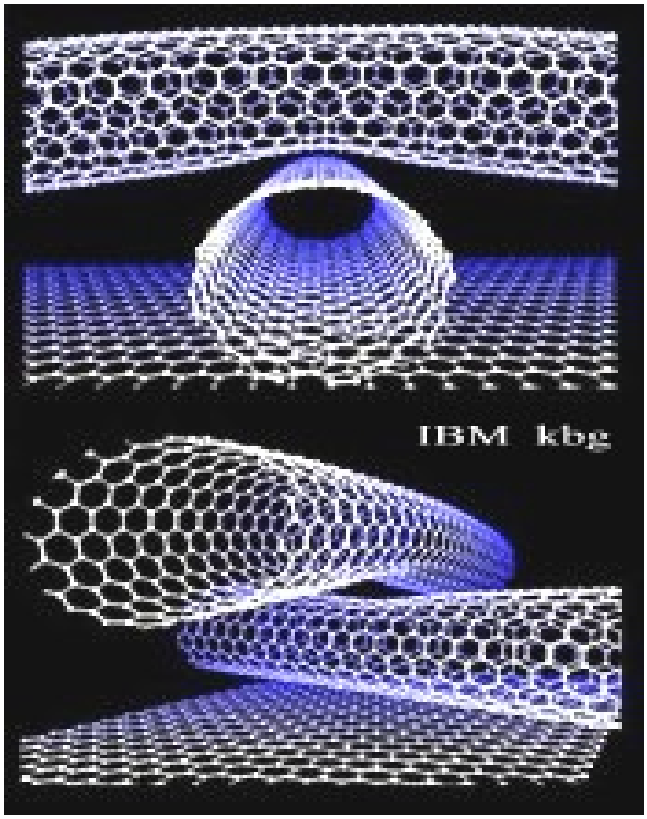

Figure 6 – CNT – IBM Corp.

THE TELECOM INDUSTRY

Internet telecom is still struggling, especially in the USA where the industry and investors had a "sanity lapse" and overbuilt, and overspent to produce the unfortunate "supernova effect". One reason for overcapacity may have been that the technology was too good. Wave Division Multiplexing (WDM) was probably the unwilling

accomplice that helped providers deploy too much capacity. Capacity had typically been increased by laying more optical fiber. That made it easy to keep track, just count the kilometers of fiber sold. But WDM allowed providers to add capacity without adding fiber. WDM hardware could let a company multiply a single fiber link capacity by 10 or even 100 times. WDM divides data into different wavelengths ("colors") that can travel over a single fiber independently. This means that 100 wavelengths allow a single fiber to mimic the capacity of 100 fibers. The incredible multiplication factors delivered by WDM was, in part, responsible for overcapacity. The situation was not as bad outside of the USA since the WDM and fiber frenzy didn't extend everywhere. In fact, some areas need to expand their networks quickly. The Optoelectronic telecom doldrums will probably last into 2004 and we should not expect to see much happen here. Most of the action will be consolidation, not technical breakthroughs, at least for a while. So the MOEMS industry must look beyond the optical switch and it already has.

Wireless telecom is another story, and a happier one. More and more, we want to be untethered. We want to link up anytime, anywhere and get anything, including colorful web pages. And we want it fast! Wireless is the only solution making it a sure bet. But what kind of wireless and what type of products? Right now, there is a free-for-all in the wireless services area and it's hard to tell who is even in the business. The logical suppliers, the phone companies, don't seem sure of where they are going. But one misstep or hesitation, and the void is filled by an outsider.

Cometa Networks (AT&T, IBM and Intel) was recently announced and the new company will certainly impact the North American market. But its not just another mobile phone service. Cometa is a short-range wireless Internet link using Wi-Fi in the 2.4 GHz band. There are already more than 12,000 "hotspots", including many Starbucks stores. A hotspot is a very localized, public access network using the IEEE 802.11b protocol (at least for now). Cometa and others are adding "hot spots" to airports, coffee shops, hotels, and just about any place where there is enough human traffic to make it viable. The Canadians are testing it in phone booth areas. Everyone seems to be moving into the hotspot space, even Nokia. To understand why this is an important event, we need to look at short-, medium-, and long-range wireless for mobile connectivity.

The Battle in Space 2.4

The radio spectrum began in the low frequency bands but has moving upstream to higher frequencies for the last 100 years. The bandwidth, or amount of data per second, is directly proportional to frequency. Going from 1 GHz to 10 GHz boosts the theoretical bandwidth by one order of magnitude. Cellular phones use several bands below and above 1 Gigahertz (GHz). So there is a good reason to move even higher, depending on the objective. The downside is that higher frequencies do not pass through materials as easily as the lower ones. So while the IEEE 802.11a format at 5 GHz has more bandwidth, the range is less. But 5 GHz is quite suitable for office linking and the IEEE 802.11a systems are showing up here and even in home systems although their 54-megabit/second bandwidth may be overkill for the typical household.

The 2.4 GHz part of the radio spectrum region has grabbed a lot of attention because it an unlicensed, or free band, also called ISM (Industrial, Scientific, Medical). Bluetooth, Wi-Fi (IEEE 802.11b) and a few other protocols reside here. Hotspot providers and office network users don't have to bid for spectrum, as was the case with the mobile phone bands. But there is a catch. The ISM bands restrict transmitter power making them only useful for short-range. So while the higher powered cellular bands have footprints measured in miles, ISM covers only a building or even less with a single transceiver.

Bluetooth (BT) falls into the very short-range zone, but its low power limit is ideal for hand-held products. BT was originally intended to replace computer cables and such, but it keeps trying to extend itself. Still, it remains a technology for device interconnection, not a full-fledge "last link", or last mile method. BT is ideal for connecting your laptop or PDA to a modern mobile phone or printer. But, Wi-Fi in the same band, is much better able to link you to the Internet or company server. So expect both BT and Wi-Fi to move into a lot of 2003 products.

IEEE 802.11b can readily handle 50 ft. links and even 300 ft if everything is just right. Our tests in the home office showed complete coverage everywhere in the two-story house and well over 100 ft. range outside. That's not bad for a $49 transceiver, or wireless access point (WAP). These systems use code division multiplexing, including BT, making them mostly immune to interference. The frequency rapidly "hops" within the band slot using pre-programmed code so that both the transmitter and receiver are in sync. Each independent system uses a different hop code and that's why so many sets can operate on the same band. Foreign signals may momentarily fall on exactly same frequency but the "noise" is too small a component to matter. It's like a meeting where each pair of attendees talks a different language and tunes the others out. The Wi-Fi format has been rapidly gaining support for home and enterprise use and now it's gaining as a public access link. Growth in 2003 will accelerate and continue for many years. Later, we'll look at the types of products that can utilize Wi-Fi.

We have moved from massive mainframes, to PCs, to "luggables", and finally to laptops that are true to their name. But while the compact laptops are smaller and lighter, they're still too big to be a "take-everywhere" computer. The Personal Digital Assistant (PDA) was the next step downward, but until recently, they didn't have the horsepower we demanded. The Pocket PC class has changed this. The modern PDAs, and new ones seem to come out every week, are almost as good as laptops. The speed has

been climbing (at 400 MHz at this time) and the software has the look and feel of desktop/laptop programs.

The Intel-powdered machines, running Windows software, are real PCs in a small form factor. The products running Apple software have also upped the horsepower to compete. Both camps are selling products that now come with built-in wireless. Lower cost models, and earlier PDAs, are easily converted to wireless systems by plugging in small external cards. The latest round of high-end PDAs has both BT and Wi-Fi internal systems. Now you can literally "Walk & Surf" using a hotspot Wi-Fi connection or a BT link to your GMS (General Mobile Service) or GPRS (General Packet Radio Service) cellular phone. We need to mention that even the newest mobile phone services, like GPRS, are much slower than Wi-Fi (11 megabits/sec. Vs. 50 – 120 kb/sec.), so the hotspots will thrive. You can also add a card to a PDA to get directly to the mobile phone system. And once you are linked to the cellular site, an earphone and software turn the PDA into a sophisticated telephone for those who want to converge. But mobile phone manufacturers also want some high ground and are offering Internet-ready products with color screens that seem to be morphing into PDAs.

We will see more and more convergence as components become denser. The PDAs are not only turning into phones, they can serve as music players, books (e-book reader) and voice recorders. You don't even need to bring a stand-alone camera on trips. Just plug a small camera module into your PDA or cellular phone. Now you can take a picture, or video, and send it down the Internet highway, all in a few seconds. And if you are lost, just plug in the GPS module.

These new mobile products and other wireless devices will be the stars of 2003. We want our e-mail and websites in our pocket and hand. Many will pay the modest price for the hardware and the service. But now that DELL has just attacked the PDA market with a "Wintel" product for about $200, this is going to be a hot area. Figure 7 shows one of the newest, full-featured PDAs, the Compaq H5450 with BT, Wi-Fi and biometric security. But is the pocket PC the final step? Too big, you say. How about a PDA watch? See figure 8.

Figure 7 – iPaq H5450 – Hewlett Packard

Mobile and wireless systems will be the catalyst, but there are other telecom products to watch. What about games? But are games a telecom product? How about X-Box-Live and the other real-time game products? They're a bit like the old Kodak Brownie camera whose purpose was to sell film. Aren't the linked game boxes there to sell software and telecom services? And if we keep pumping up Internet traffic, especially with bandwidth gluttons, will it chew up that excess capacity that's been a problem? Of course it will! Everything is connected to the Internet making it the worldwide hub. Sooner or later, we will run out of capacity.

Figure 8 – PDA Watch – Fossil, Inc.

Security

Technology is helping with security at all levels. By the time you've walked through a mall, you have been captured and maybe digitized 100 times. Your digitally-coded mug shot was probably checked against a "bad guy" file before for you're near your gate at Logan Airport. And biometrics is moving into all sectors. You will be verified-certified by measuring your fingerprint, eyeball, or face sometime soon. Like it or not, we have moved into the era of digital verification. You will need a biometric check to buy merchandise, start your car, get into an airport, go into your office, and even run your computer. Some are in place and the others are likely. And if you think that biometrics is just for the big stuff with complex hardware and software, check out the iPaq 5450 PDA, the one with BT and Wi-Fi. It already has a biometric security checker that asks for your finger print impression, right on the screen before letting you into the system.

Satellite Radio

Radio is making a comeback, as well it should. We spend so much time driving that vocal communications is surging. We have also become accustomed to cable or satellite TV with many channels and great reception, so why not boost mobile audio performance? That's exactly what satellite radio is all about. Satellites are transmitting 100's of stations

in clear digital. Buffering, or downloading, can take care of problems normally caused by obstacles that temporarily block the signal. With heavyweights like Delphi (GM) in the, game, expect success.

But before we leave the consumer product area, lets check out general entertainment. There are plenty of new gadgets, but where does MEMS and MOEMS fit. MEMS accelerometers are making game controllers better and robot pets more realistic. The game controllers, including gloves, use 2-axis accelerometers to sense hand and control device movement. And the high-tech robo-pets use MEMS to sense their own motion. The Sony dog has 3 MEMS chips from the last count – see Figure 9. Even experimental PDAs have motion sensors that can be used for scrolling action and even security.

Figure 9 – Aibo Dog - Sony

Now let's see where MOEMS is playing. The answer is in a theater near you. The digital theaters, and there are now several dozen, have converted to high-density MOEMS micro-mirror projector chips. Texas Instruments is the leader with its 1.4-million mirror DLP™ (Digital Light Processor) MOEMS cinema chips, but Kodak and others also want to move into the movie space. The digital movie action is quicker, crisper, and projection is much brighter. Movie film is more easily destroyed by powerful light source heat than inorganic chips. Several viewers said that they didn't notice a big difference in digital until they went back to an analog film theater. The conventional cinema looked dull and washed out. We can expect to see the digital cinema slowly replace the old Edison movie technology.

But there is one more important consideration. How do the digital movies get to the theater? Well, for now, its as recorded media that's shipped just like movie film. But in the near future, and maybe it's already happened, it can be delivered over the Internet. And if high-resolution digital cinema can get to the local cinema, why not into your home? That's just what the MOEMS cinema developers are thinking and that's why HDTV is having a go at this technology. HDTV sets are now available that employ MOEMS modules. Time will tell which technology wins the home entertainment race, but MOEMS scales best. A chip that is only about 1" square, delivers 1,400,000 pixels of color picture, and that's a big picture – see Figure 10. Since projection is used, the chips will stay small, maybe even get smaller and denser. The flat screen technologies must build screens as big as the picture. We'll have to watch this all play out, but MOEMS is going to be hard to beat. A Samsung ad tells us to, "Enjoy 50" projection TV in the space of a much smaller TV…it takes up a fraction of the space…[because it] uses a postage stamp-sized Digital Micromirror Device…". Figure 11 shows a MOEMS-powered HDTV.

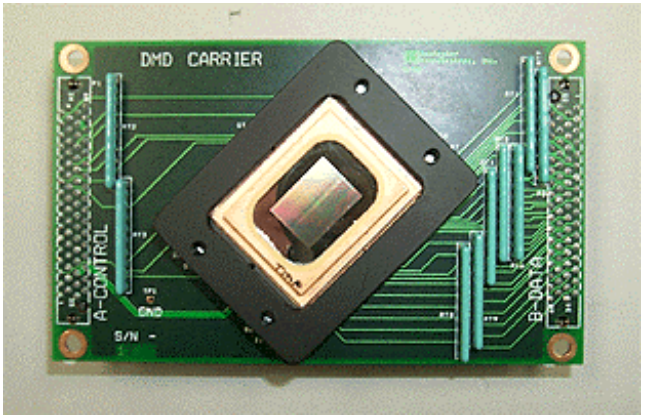

Figure 10 – DLP MOEMS Chip – Texas Inst.

Figure 11 – MOEMS HDTV

Bio-med and MEMS

We want to stay healthy while we're being entertained, and the micromechanical technology can help here, too. MEMS devices are the right size to interact with life forms. MEMS can pump blood, slice blood cells, help synthesize drugs and aid in the analysis of all kinds of things. This will be a slow-to-grow, but large and significant field for MEMS and probably Nanotech. This won't happen in 2003, but in our lifetimes.

MOVING DOWN TO THE LAST FRONTIER

Finally, we will look at Nanotechnology based products, and ignore the science fiction aspects, whether from "scientists" or writers. Nanopowders will almost certainly make materials better and there are already some nano-composites out there. Figure 12 shows GE's very shatter-resistant nano-ceramic that mimics nature's seashell structure also shown. But nano-electronics will be the exciting field to watch. IBM, AT&T and a few universities have already announced transistors and other devices based on Nanocarbon Tubes. The important difference for NCT devices is mostly size, not performance. Nano-electronics could increase density by orders of magnitude. The CNTs are only a few nanometers wide. Figure 13 shows a concept drawing and Figure 14 shows an actual transistor. The day may come when carbon nanostructures replace silicon semiconductor transistors. But don't forsake Silicon Valley for Carbondale just yet. IBM has also announced the world's smallest transistor made from silicon. But CNT may also revive a 100-year old product. Figure 15 shows the equivalent of a triode amplifier analogous to old vacuum tube amplifiers but made from NCT with no vacuum required. Carbon-based devices could replace silicon semiconductors, but IBM is backing both elements and is pursuing NCT and Si based nano-transistors. Figure 16 shows the nano-silicon transistor.

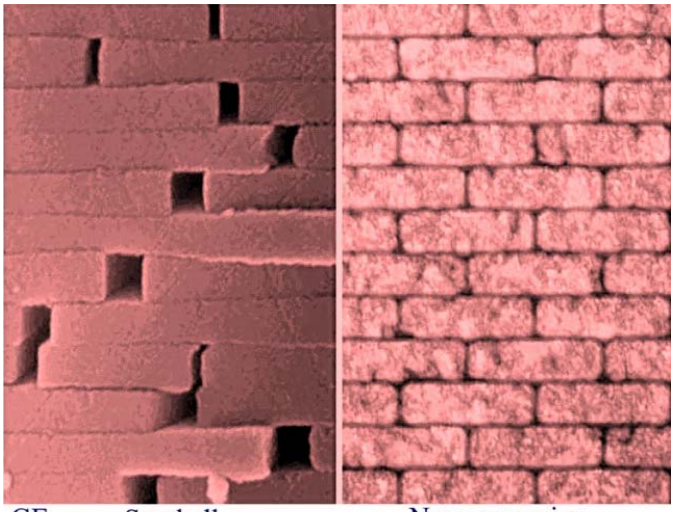

Figure 12 Nano-composite vs. seashell

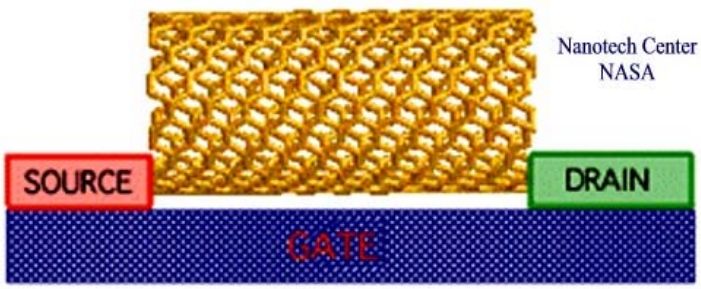

Figure 13 – CNT Transistor Diagram - NASA

FUTURES

A brave new, bright and tiny world lies ahead viewed from the ET perspective. The micromechanical and nanotechnologies will serve many masters and enable uncountable new products. Our new suite of ETs will boost communications, increase portability, help us stay or get healthy, and keep some of us entertained. The world of technology is still only embryonic and the best is yet to come. And Feynman was right, there's plenty of room at the bottom.

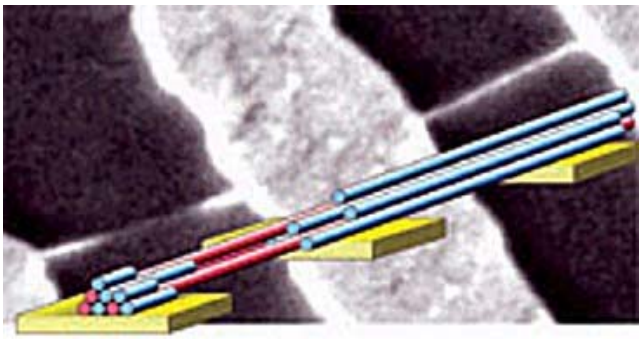

Figure 14 – CNT Transistor - IBM

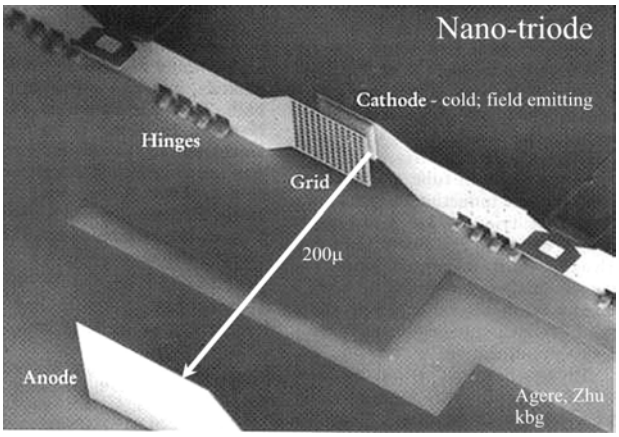

Figure 15 – IBM CNT Triode – AT&T

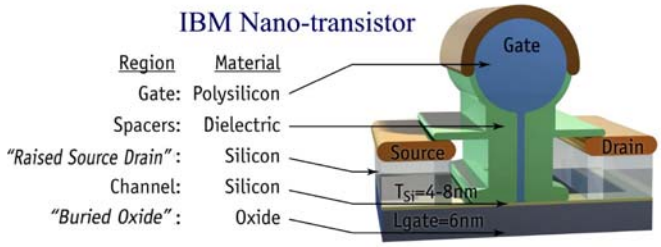

Figure 16 – Nano Si Device - IBM