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Research Paper

STUDY AND OVERVIEW ABOUT MOLECULAR MANUFACTURING SYSTEM

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Molecular manufacturing is a branch of nanotechnology that involves the use of nanoscale (extremely small) Machine tools and non-biological processes to build structures, devices and systems at the molecular level. Nanoscale objects have dimensions on the order of a few nanometers (nm) or less, where 1 nm is equal to a billionth of a meter (10^{-9} m). Molecular manufacturing is distinct from nanoscale technology, another major branch of nanotechnology in which standard size tools are used to manufacture simple nanoscale structures and devices. Two technological capabilities are key to economically viable molecular manufacturing, and are essential to reap the tremendous benefits and the full potential of manufacturing in the 21st century. The first key is the ability to fabricate physical structures with molecular precision. The second key is the ability to fabricate massive quantities of molecularly precise structures, or to assemble larger objects from vast numbers of molecularly precise smaller objects. We will need a theoretical and experimental program to develop molecularly precise fabrication of diamondoid structures using machine-phase nanotechnology. We will also need a theoretical and experimental program to develop methods for massive parallelization of these newly developed machine-phase techniques for molecularly precise fabrication. This combined effort will result in the full realization of the tremendous potential for 21st century manufacturing

Keywords: Anon, Molecular, Nanofactory, Nano machinery, Nano robots

INTRODUCTION

Nanotechnology is the premier economic driver for manufacturing in the 21st century. The National Nanotechnology Initiative defines "nanotechnology" as research and technology development in the length scale of approximately 1 to 100 nanometers, with the overall objective of providing a fundamental understanding of phenomena and materials at the nanoscale and to create and use structures,

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devices and systems that have novel properties and functions because of their small or intermediate size. According to the NNI: "Nanotechnology research and development includes manipulation under control of the nanoscale structures and their integration into larger material components, systems and architectures. Within these larger scale assemblies, the control and construction of their structures and components remains at the nanometer scale. In some particular cases, the critical length scale for novel properties and phenomena may be under 1 nm (e.g., manipulation of atoms at ~0.1 nm) or be larger than 100 nm (e.g., nanoparticle reinforced polymers [with] unique features at ~ 200-300 nm as a function of the local bridges or bonds between the nanoparticles and the polymer)." A self-replicating system achieves massively parallel assembly first by fabricating copies of itself, and allowing those copies to fabricate further copies, resulting in a rapid increase in the total number of systems. Once the population of replicated manipulator systems is deemed large enough, the manipulator population is redirected to produce useful product objects, rather than more copies of it.

MOLECULARLY PRECISE FABRICATION

There are two principal techniques for achieving molecularly precise fabrication of physical structures. These two techniques are known as self-assembly and positional assembly. Molecular self-assembly involves stirring molecular parts together and, by clever design of those parts, making parts that spontaneously assemble into the desired result. Self-assembly is a probabilistic process in which only the final state (the desired end configuration), and not the pathway taken to it, is specified. Molecular self-assembly is a strategy for nanofabrication that involves designing molecules and supramolecular entities so that shape- and charge-complementarily causes them to spontaneously aggregate into desired structures. Molecular self-assembly is experimentally accessible today. Indeed, virtually all of the structures fabricated in contemporary nanotechnology research (e.g., nanotubes, dendrimers, and functionalized nanoparticles) are produced via self-assembly. Molecular positional assembly—also known as mechanosynthesis (Figure 1) is experimentally accessible today. However, far less progress has been achieved. In part, this is because much of the work to date has employed more specialized laboratory equipment such as Scanning Probe Microscopes (SPMs), high-vacuum systems, and ultra-low-temperature chambers. In the future, and after a great deal of further development, the deterministic positional assembly process could achieve remarkably high reliability, permitting the direct fabrication of relatively large structures. With suitable tool tips, redesign of new product structures should be relatively simple and quick, allowing rapid prototyping of new designs and a far greater range of atoms and materials should become accessible for molecularly precise fabrication. Robotic assembly of nanostructures using the atomic force microscope. Programmable positional assembly at the molecular scale is the central mechanism for achieving both great flexibility and the ultimate in precision and quality in manufacturing (Figure 2) while ubiquitous at the scale of centimeters and meters, positional assembly at the molecular

Figure 1: Nano Mechanical Device

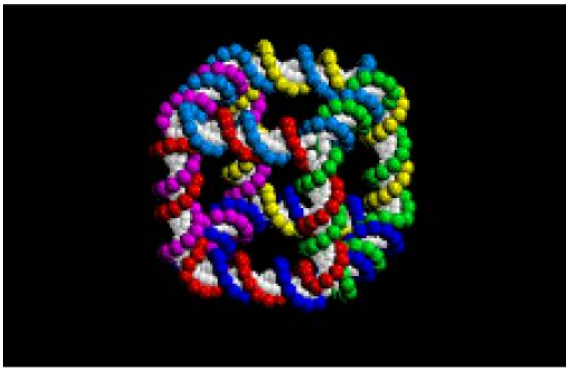
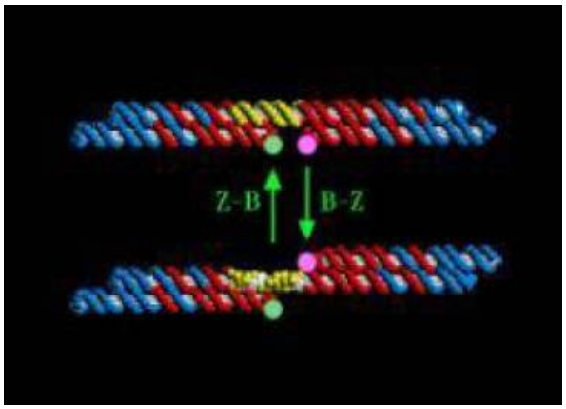


Figure 2: Z B Transition



scale is still rudimentary—but its promise is immense. When these molecules bump into the surface they change it, either by adding, removing, or rearranging atoms. By carefully controlling the pressure, temperature, and the exact composition of the gas in this process, called chemical vapor deposition or CVD, we can create conditions that favor the growth of diamond on the surface.

But randomly bombarding a surface with reactive molecules does not offer fine control over the growth process and is more like building a wristwatch with a sand blaster. To achieve molecular precise fabrication, all chemical reactions must occur at precisely specified places on the surface. A second problem is how to make the diamond surface reactive at the particular spots where we want to add another atom or molecule. A diamond surface is normally covered with a layer of hydrogen atoms. Without this layer, the raw diamond surface would be highly reactive because it would be studded with unused (or "dangling") bonds from the carbon atoms. While hydrogenation prevents unwanted reactions, it also renders the entire surface inert, making it difficult to add carbon (or anything else) to it. We could use a set of molecular-scale tools that would, in a series of well-defined steps, prepare the surface and create hydrocarbon structures on a layer of diamond, atom by atom and molecule by molecule. The first step in the process might be to remove a hydrogen atom from each of two specific adjacent spots on the diamond surface, leaving behind two reactive dangling bonds. This could be done using a hydrogen abstraction tool—an as yet theoretical molecular structure that has a high chemical affinity for hydrogen at one end but is elsewhere inert. The tool's uncreative region serves as a handle. The tool would be held by a molecular positional device, initially perhaps a scanning probe microscope tip but ultimately a molecular robotic arm, and moved directly over particular hydrogen atoms on the surface. One suitable molecule for a hydrogen abstraction tool is the acetylene radical—two carbon atoms triple bonded together. One carbon would be the handle, and would bond to a nanoscale positioning tool. The other carbon has a dangling bond where a hydrogen atom would be in ordinary acetylene. The environment around the tool would be inert

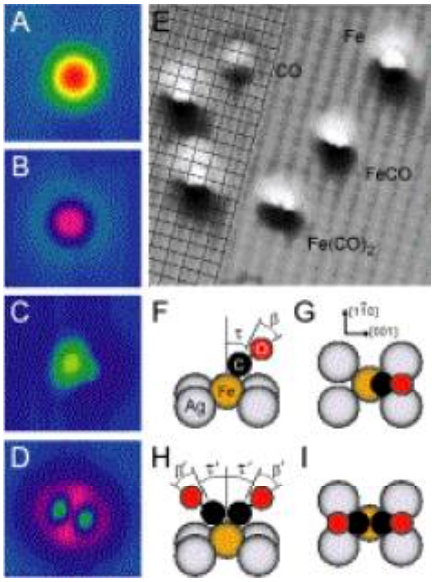
(e.g., vacuum or a noble gas such as neon). After a molecularly precise structure has been fabricated by a succession of hydrogen abstractions and carbon dimmer depositions, the fabricated structure must be passivity to prevent additional unplanned reactions. While the hydrogen abstraction tool is intended to make an inert structure reactive by creating a dangling bond, the hydrogen donation tool does the opposite: makes a reactive structure inert by terminating a dangling bond. Such a tool would be used to stabilize reactive surfaces and prevent the surface atoms from rearranging in unexpected and undesired ways. The key requirement for a hydrogen donation tool is that it includes a weakly attached hydrogen atom. Many molecules fit that description, but the bond between hydrogen and tin is especially weak. A tin-based hydrogen donation tool should be effective.

These three molecular tools, plus a few others, should enable us to make a wide range of molecularly precise stiff structures—but only those that are composed of hydrogen and carbon. This is a far less ambitious goal than attempting to use all 90+ natural chemical elements in the periodic table. In exchange for narrowing our focus to this more limited class of structures, we make it much easier to analyze in detail those structures that can be fabricated and the synthetic reactions needed to make them. Diamond and its shatterproof variants fall within this category, as do the fullerenes (sheets of carbon atoms rolled into spheres, tubes, and other shapes). These materials can compose all of the parts needed for basic nanomechanical devices such as struts, bearings, gears, and robotic arms. Later on, a handful of additional elements can be added, such as dopant atoms to fabricate diamond electronic devices. These and related structures, composed primarily of carbon and hydrogen in combination with a few atoms of nitrogen, oxygen, fluorine, silicon, phosphorus, sulfur, chlorine, or other elements, constitute what we call the class of "diamondoid" materials. The end result of this development process would be a basic nanofactory or molecular assembler that employs machine-phase nanotechnology (e.g., nanoscale gears, struts, springs, motors, casings) to fabricate molecularly precise diamonded structures, following a set of instructions to build a desired specific design. The magnitude of this challenge should not be underestimated. Present proposals for a nanofactory or molecular assembler able to fabricate diamondoid structures involve at least hundreds of millions of atoms—with no atom out of place. Even a simple robotic manipulator arm, which might be composed of only a few million atoms, would have to be accompanied by other components. The robotic arms might work in a vacuum, dictating the need for a shell around the arm to maintain that vacuum. Essential ancillary subsystems might include acoustic receivers, computers, pressure-actuated ratchets, and binding sites. If each operation, such as hydrogen atom abstraction or carbon dimer placement, typically handles one or a few atoms, then the error rate must be less than one in a billion (Figure 3).

PATHWAY TO MASSIVELY PARALLEL ASSEMBLY

Economically viable molecular manufacturing systems based on molecularly precise

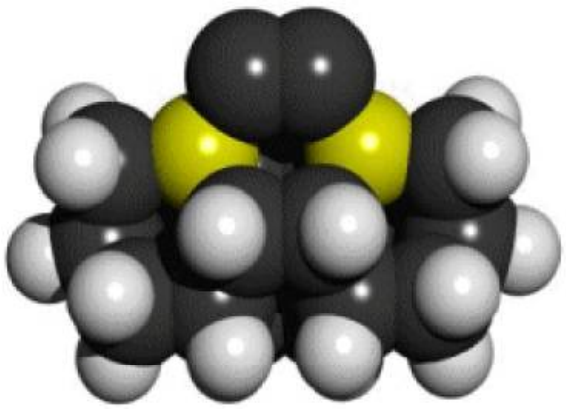
Figure 3: Fe (CO_2) Molecule



massively parallel assembly are likely to take longer to develop than the usual five to ten year time horizon of the private sector. The private venture capital sector has shown considerable enthusiasm for funding nanoscale science and engineering projects that focus on novel electrical or physical properties of nanoscale materials. But they are not focusing on the high-risk, high-payoff opportunity of developing molecular manufacturing machine components and systems with moving parts. There are some European and Japanese initiatives to develop molecular manufacturing components and systems. The key rationale for US government funding is that molecular manufacturing might not happen first in the US, or will happen much more slowly in the US, if we rely on the private sector for initial R&D stage funding. The question of who develops this technology first has profound economic, security, military, and environmental significance.

A successful molecular manufacturing system that might be deployed in the 2010s or 2020s could be described and analyzed today. Such a system would almost certainly be composed mostly of systems and subsystems that are not experimentally accessible at present, for the simple reason that we cannot yet build the relevant components. But if we are to think about and analyze systems that we cannot build today, and if we are to do so with any certitude, then we must initiate a carefully conceived theoretical and computational R&D program expressly for this purpose. Existing tools in computational chemistry can be harnessed to analyze molecular structures, regardless of whether or not those structures are immediately buildable (Figure 4). Computational modeling of known experimentally accessible structures gives us confidence about the capabilities (and limits) of the modeling software, and permits us to evaluate structures that have not yet been made—and perhaps cannot directly be made using our current 20th century technology base. The value of such theoretical and computational work, particularly when used to assess systems that exceed our immediate experimental capabilities, is sometimes

Figure 4: Micro Synthesis



debated. But the alternative is to abandon active investigation of systems and structures that cannot be built today. Inability to think systematically about what cannot yet be built is very likely to delay our ability to build it. If we are to build machine-phase molecular manufacturing systems in the next two decades—systems that are experimentally inaccessible today—then methodical design work on such systems is both necessary and urgent (Figure 5).

Figure 5: Millipede Concept

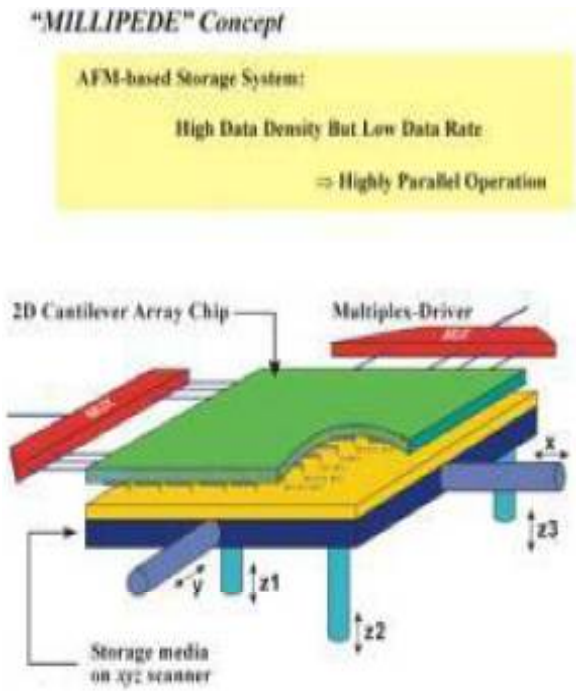


Figure 6: Nano Exponential

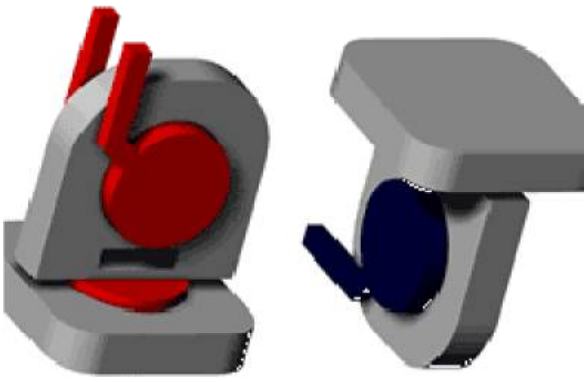
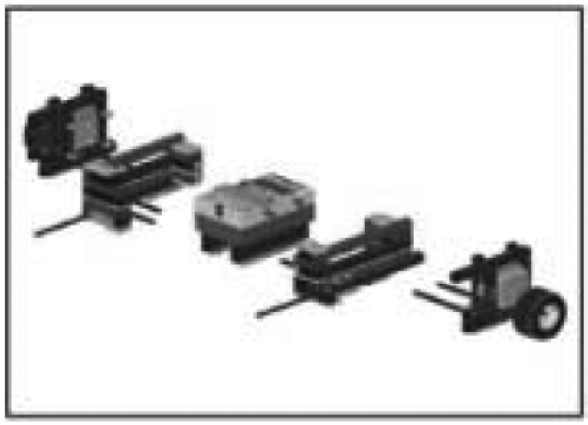


Figure 7: Nano Exponential Assy

Figure 8: Kinematic Replicator



APPLICATIONS

The end result of the research program proposed here will be molecular manufacturing systems capable of producing macroscale quantities of molecularly precise diamondoid structures. Nanofactories or molecular assemblers will make possible the manufacture of fundamentally novel products having the intricate complexity currently found only in biological systems, but operating with greater speed, power, reliability, and, most importantly, entirely under human control (Figures 6 to 8).

Moics and Molecular Computers

The manufacture of computer chips for data storage and computation will undergo a profound change. There are fundamental limits to further improvements in conventional lithography, the current process for chip manufacture. If improvements to computer hardware are to continue at the present pace, in a decade or so lithography must be replaced by some new manufacturing technology the current process for chip manufacture. If improvements to computer hardware are to continue at the present pace, in a decade or so lithography must be replaced by some new manufacturing technology. Designs for computer logic elements composed of fewer.

Nanomedicine

Once we learn how to design and construct complete artificial nanorobots using strong diamondoid materials, nanometer-scale parts, and onboard subsystems including sensors, motors, manipulators, power plants, and molecular computers, the practice of medicine will be forever changed. One example is the artificial mechanical red cell called a respirocyte still entirely theoretical, the respirocyte is a micron-wide spherical nanorobot made of 18 billion atoms precisely arranged in a diamondoid structure to form a tiny tank for compressed gas that can be safely pressurized up to 1,000 atmospheres. Several billion molecules of oxygen and carbon dioxide can be absorbed or released from the tank in a controlled manner using computer-controlled molecular pumps powered by glucose and oxygen. External gas concentration sensors would allow respirocytes to mimic the action of the natural hemoglobin-filled red blood cells, with oxygen released and carbon dioxide absorbed in the tissues, and vice versa in the lungs. Each respirocyte can hold 236 times more gas per unit volume than a natural red cell, so a few cubic centimeters injected into the human bloodstream would exactly replace the gas carrying capacity of the patient's entire 5.4 liters of blood. A half-liter dose could keep a patient's tissues safely oxygenated for up to 4 hours in the event that a heart attack caused the heart to stop beating. Or this large dose would enable a healthy person to sit quietly at the bottom of a swimming pool for four hours, holding his breath, or to sprint at top speed for at least 15 minutes without breathing.

Other proposed medical nanorobots potentially offer equally astonishing performance improvements over nature. For instance, nanorobotic phagocytes (artificial white cells) called microbivores could patrol the human bloodstream, seeking out and digesting unwanted pathogens including bacteria, viruses, or fungi. Each one of these nanorobots could completely destroy one pathogen in just 30 seconds—about 100 times faster than natural leukocytes or macrophages—releasing a harmless effluent of amino acids, mononucleotides, fatty acids and sugars. It will not matter that a bacterium has acquired multiple drug resistance to antibiotics or to any other traditional treatment. The microbivore will remove it anyway, achieving complete clearance of even the most severe septicemic infections in minutes to hours, as compared to weeks or even months for antibiotic-assisted natural white cell defenses—and without increasing the risk of sepsis or septic shock. Related nanorobots could be programmed to recognize and digest

cancer cells, or to mechanically clear circulatory obstructions in a time scale on the order of minutes, thus quickly rescuing the stroke patient from ischemic damage. Nano robotic clottocytes (artificial mechanical platelets) could make possible complete hemostasis in just 1 second, even for moderately large wounds, a response time 100-1000 times faster than the natural system. Clottocytes may perform a clotting function that is equivalent in its essentials to that performed by biological platelets, but at only 0.01% of the bloodstream concentration of those cells or about 20 nanorobots per cubic millimeter of serum. Hence clottocytes appear to be about 10,000 times more effective as clotting agents than an equal volume of natural platelets.

Aerospace and Defense

Natural diamond is expensive, can't be formed into arbitrary desired shapes, and readily shatters. Nanofactories or molecular assemblers will allow the inexpensive fabrication of shatterproof diamond (e.g., diamond fibers) in exactly the shapes we want. This would allow the design and construction of a space shuttle with a structural mass just 1/ 50th of today's version without any sacrifice of strength. Made-to-order diamondoid assemblies would benefit all load-bearing structures, and most of the mass in most of our products is load bearing. Beams, struts, buildings, cars, planes, boats and almost all other products would benefit—for example, automobiles could weigh less than the weight of their passengers, and 1-kilogram bicycles would delight racers. The most dramatic improvements are possible for rockets, where the strength-to-weight ratio and the cost of components are critical. Personal ground-to-orbit vehicles the size of a station wagon with launch costs of ~$1/kg to orbit should be feasible, allowing easy personal access to space.

Environment

Nanofactories and molecular assemblers are the ultimate "green" technology. Clean assembler-based factories using molecularly-precise feedstocks would eliminate the pollution typically produced by traditional bulk manufacturing and would allow complete recycling of previously manufactured molecular structures. Products could be manufactured and used without generating wastes or noxious effluents, with high process efficiency and lighter materials thus reducing both material and energy consumption. Forced flow of polluted water through nanopore filters, possibly using simple mechanical power supplied by people or animals, could provide a cheap source of fresh potable water for impoverished third-world populations. Molecular nano robots also could enable comprehensive environmental remediation, quickly and cheaply cleaning up existing pollution and toxic wastes left behind from the 20th century.

Energy

Low cost solar cells and batteries produced by molecular manufacturing could replace coal, oil and nuclear fuels with clean, cheap and abundant solar power. Humanity currently consumes about 10 terawatts of power, but over 100,000 terawatts of solar energy continuously fall on the Earth, most of it unused directly by man. Nano factories or molecular assemblers could radically alter the economics of energy production. We already

know how to make efficient solar cells. Nanotechnology could cut costs, finally making solar power economical. Here we need not make new or technically superior devices—just by making inexpensively what we already know how to make expensively, we would move solar power into the main stream.New fabrics and building materials can be embedded with billions of tiny motors, sensors, and even computers, allowing our clothing, furniture, and houses to react instantly and intelligently to external conditions and to our ever-changing needs.

CONCLUSION

It seems likely that the development of machine-phase nanotechnology will require time, focus, and resources. The creation of nuclear weapons took billions of dollars and a very focused development project. The Apollo program likewise took a focused effort over many years, along with billions of dollars and vast amounts of creative talent. The unfolding of the computer industry, while following a very different pattern (private versus governmental, incremental "pay as you go" versus large up-front funding), also involved major funding and many years of focused effort. It is too early to know exactly what pattern the development of machine-phase nanotechnology will follow, but it is not too early to observe that it is likely to require major resources. Whoever makes the decision to commit these resources is unlikely to do so unless there is a clear picture of both the goal and how to achieve it. We will need a theoretical and experimental program to develop molecularly precise fabrication of diamondoid structures using machine-phase nanotechnology. We will also need a theoretical and experimental program to develop methods for massive parallelization of these newly developed machine-phase techniques for molecularly precise fabrication. This combined effort will result in the full realization of the tremendous potential for 21st century manufacturing, yielding inexpensive and transformative products in the computer, medical, aerospace, defense, environmental, energy, and household sectors of the economy.

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