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Research Article

Interwining Two Technologies: 3D Printed Nanotechnology

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A B S T R A C T

Three-Dimensional (3D) bioprinting is an additive manufacture technique with huge potential in the development of custom tissue scaffolds and medical devices, particularly in tissue engineering and regenerative medicine, for different biomedical applications. This emerging technology has stimulated different fields of biomedical engineering as well as translational medicine because of its new capabilities, such as high speed, slim resolution and design specificity. Over the past years a huge improvement in the therapeutic effectiveness of three-dimensional tissue scaffolds has been seen through the integration of Nanotechnology concepts and nanomaterials with 3D biopression techniques. Because of their high surface to volume ratios and quantum containment effects, nanotechnological methods and nanomaterials have special physical, chemical and biological properties. The combination of nanomaterials and techniques for 3D bioprinting however improves the development of 3Dbioprinted fabrics with improved physicochemical and biological properties. Like 3D printing, nanotechnology is one of the most extension fields in recent years for study and progress. Both are moving towards revolutionizing different fields, including medicine, manufacturing, global economics and space exploration. This paper discusses the ways in which these two potential revolutions can be connected and interwoven with nanotechnology and 3D printing.

Keywords: 3D Printing, Nanotechnology, Revolution, Bioprinting

Introduction

The National Nanotechnology Initiative's general concept is that nanotechnology consists of at least one-dimensional material processing ranging from 1 to 100 nanometers. Nanotechnology, as in 3D printing, can deliver a broad range of applications, including surface, organic, molecular biology, semiconductor, moleculomedical, nanomedical, nanoelectronics, biomaterials, processing of electricity, consumer goods, etc. The use of nanotechnology can also be achieved.[1]

Nanoscale Additive Production

Additive nanoscale processing is not a matter of the future any longer. To accomplish this, there are various techniques in place:

- DNA: chemically, if you're thinking about, Nature is composed of billions of nanoscale 3D printers that create 3D digitally based structures (the DNA is like your STL file in this scenario!). We can use proteins to create nanomachines
- By producing layer by layer and using a concentrated electron beam inducted deposition of layers that are one atom thick (FEBID)
- Two polymers based on the interaction of femtosecond laser radiation, a technique similar to Selective Laser

Sintering (SELS), which causes a highly localized chemical reaction that leads to a polymerization of photosensitive material up to a current resolution of 100nm

The 3D prints of nano objects are possible with these three techniques.

Just to offer a few instances:

- Jan Torgersen developed a 3D printer which can produce nano-scale artifacts for a broad range of photonics, surface modifying and biomedical engineering applications. It's the fastest of its kind today and closer to commercial applications with technology. A video showing the design of a race car model on the scale of human hair was recently shown the way it performs. He speaks of it in his TED Talk: 'The race downwards'[2]
- Nanoscribe is used for nanoscopic stereolithography. With their Photonic Specialist GT machine you can build objects as small as a few microns

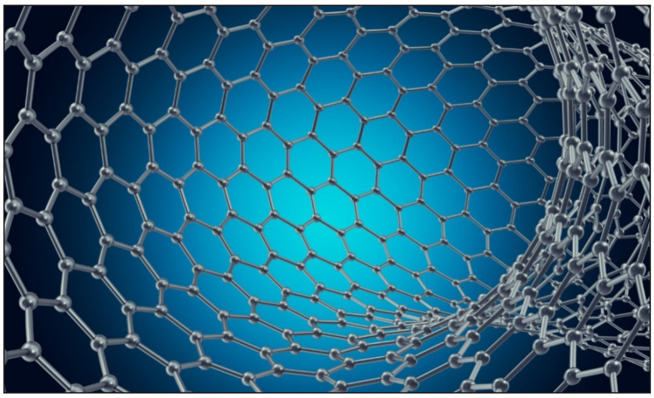

Figure 1.Nanoscribe's 3D Printed Nano Plane

Three-Dimensional (3D) bioprinting is an additive manufacture technique with huge potential in the development of custom tissue scaffolds and medical devices, particularly in tissue engineering and regenerative medicine, for different biomedical applications. This emerging technology has stimulated different fields of biomedical engineering as well as translational medicine because of its new capabilities, such as high speed, slim resolution and design specificity. Over the past years a huge improvement in the therapeutic effectiveness of three-dimensional tissue scaffolds has been seen through the integration of Nanotechnology concepts and nanomaterials with 3D biopression techniques. Because of their high surface to volume ratios and quantum containment effects, nanotechnological methods and nanomaterials have special physical, chemical and biological properties. The combination of nanomaterials and techniques for 3D bioprinting however improves the development of 3Dbioprinted fabrics with improved physicochemical and biological properties. Like 3D printing, nanotechnology is one of the most extension fields in recent years for study and progress. Both are moving towards revolutionizing different fields, including medicine, manufacturing, global economics and space exploration.[3] This paper discusses the ways in which these two potential revolutions can be connected and interwoven with nanotechnology and 3D printing.

Improvements in Nanotechnology for 3D Printing Materials

3D printed materials can also be enhanced with nanotechnology. For example, the use of carbon filaments for FDM 3D printing has been studied for the electrically conductive application of this filament.

Carbon nanotubes can also be used to stabilize 3D printed plastic structures using FDM: the carbon nanotube ink coats the plastic filament. This ink is then subjected to microwaves: carbon nanotubes are especially quick to heat while microwaves are being used, while FDM plastic does not.[4] This subtly melts and ties the plastic filament together, making the finished product even more solid.

Concrete applications of already developed or predicted 3D printed nanotechnology.[5]

Applications are large, probably go beyond what we can now imagine. To give only a few examples:

- In 2013, American researchers could use ink containing lithium-ion nanoparticles to print extra powerful sand grain-based batteries. You can easily imagine that batteries such as very small cameras are used in nanoelectronics
- Another application is filtration systems: nano-fluid filters in channels which are only a micrometer wide can be generated on the Nanoscribe unit
- Printable electronics: 3D printing of flexible displays or batteries, so lightweight it can be rolled up and fit into your pocket, in future

3D printing and nanotechnology have many benefits and uniquely appealing features. Nanotechnology has in particular been opening up a large variety of routes over recent years for decaying material and system measurements, while 3D printing has rendered it difficult for classical subtractive processing techniques to create objects with shapes. The potential combination of both fields will yield unique scientific and industrial results that have undoubtedly become of great interest.[6] In a multitude of applications, 3D printing and nanotechnology have been exploded, attracting a heavy biomedical attraction.

3D Printer Spectrum

In recent years, three (3D) printing methods have received considerable attention, with some technology ingredients maturing and with some long-term patents expiring which allows hobbyistic use. Associated approaches have been rightly labeled 'game changes' bypassing conventional development paradigms and allowing a variety of new features. The current focus of this series of manuscripts is on progress made in the fields of science and engineering, in turn, on several fields of daily life.[7]

When 3D is stated, this is specifically connected with printing, in a way, the magic that we see with the naked eye of objects. We strongly believe that micro, nano 3D and 2D printing offers our science and engineering research with a reasonably unconditional environment, repeating the popular exhortation from the Nobel Prize-winning late Prof. Feyman, 'There is plenty of space at the bottom.'[8] The discrepancy between what is widely known as 2D printings and its 3D analog is typically the sémantics of the deposited material and time-scale immobilization. Technically, 3D-scale are in reality the majority of 2D prints (or materials). They have a multi-scale area and a height (in many cases just a few nanometers!). This is applicable to many material printing techniques, including roll-by-roll and inkjet printing.

Nanotechnology 3D Printing Mixes

Two-photon lithograph (TPL) prints a hundredth of human hair width in sections.

Researchers at the LLNL have improved two-photon lithography (DPT) capable of creating nanoscale features that is smaller than 100% human hair width, which has a high-resolution, 3D printing technique. LLNL is the most comprehensive technology.

In the process of curing and printing photoresistive materials TPL usually includes a fine glass slide, a lens and an immersion oil for the laser light to concentrate on a fine point. It produces smaller features than the laser light point (less than 150 nm), an amount that cannot be matched by any other printing device. The technique circumvents the other method's normal diffraction limit because photosist material, which heals and hards structures (formerly trade secrets) simultaneously absorbs two photons rather than one.[9-10]

Previous techniques have constructed structures from the ground up that restrict the height of the objects, as there is normally 200 microns or less between glass toboggan and the lens. The enhanced procedure directly positions the resistor material on the lens and concentrates the laser over the resistor, this enables researchers to print objects multifunctional in height. Furthermore, researchers were able to modify and boost the amount of radiation that the photopolymer resists can absorb, thereby enhancing more than 10 times the attenuation of typical photoresists.

The laser light refracts as it passes through the material of the photographers, so that the laser will go unimpeded through the refractive index of the material of resistance to the immersion medium of the lens. Matching index opens up the opportunity to print larger components with features of 100 nanometres.

Sourabh Saha, one of the researchers, says, "Most researchers who want to use two-photon lithography to print functional 3D structures want parts greater than 100 microns," The only constraint is that of speed, it's a trade-off but now that we know how to do this, we can diagnose and improve the process."With these index-matched resists, you can print the structures as high as you want. The only limitation is that of speed. It's a tradeoff, but now that we know how to do that, we can diagnose and improve the process."The index resistant is that you can print structures as high as you want.[11-13]

When tuning X-ray absorption, researchers may use computed x-ray tomography as a method to diagnose the inside of the parts or to analyze objects printed 3D inside the body including stents, joint replacements and bone scaffold. These techniques could also build and test the internal structure of targets, optical and mechanical metamaterials and electrical batteries printed 3D, for the National Ignition Facility.

The only thing that is restricting is the time that it takes for the researchers to parallel and speed up the process. They plan to move into even smaller features to create actual, mission-critical parts using the technique.[3-5]

Small Bits, Big Results: 3D Printing and Nanotechnology:

Although often perceived as buzzwords used to create excitement around a product, 3D printing and nanotechnology are two relatively new fields that are being used in combination to create a wide range of interesting new technologies. Here we will talk about what these two disciplines are, how they're changing things up. Traditional manufacture usually takes place as a 'top-down' approach. This is where a material is removed until only the final form is left, such as carving a sculpture from a block of marble, cutting out a shape from a sheet of metal. This process can be wasteful as a lot of the time the excess material isn't recycled. Additive manufacture is the opposite of this procedure, known as 'bottom-up', with the component being built piece-by-piece or layer-by-layer, until it is fully formed. 3D printing falls under the description of additive manufacture and uses a moving head to deposit a layer of material, which is then moved up or down and a new layer is then built on top of the previous one with another pass of the printer head. The slices are built up like this and it is possible to fabricate complex structures with precise measurements. 3D printing can be used with polymers, plastics and ceramics to produce components that may not have been possible using conventional manufacturing techniques.[14]

The original idea behind nanotechnology came from a talk by famous physicist Richard Feynmann entitled “There’s Plenty of Room at the Bottom”, where he described scientists in the future manipulating individual atoms and molecules to create new materials that make use of effects only seen at that size scale. In the nearly 60 years since this lecture, nanotechnology research is pursued worldwide and brought about some significant scientific advancements. While there are a few definitions of the word, we will now use NASA’s which says it is “the creation of functional materials, devices and systems through control of matter on the nanometer length scale (1-100 nanometers), exploitation of novel phenomena and properties (physical, chemical, biological, mechanical, electrical) at that length scale.” Nanotechnologies can be manmade like carbon nanotubes for filtration, naturally occurring such as the tiny hairs on geckos feet that allow them to cling to walls.

By combining these two disciplines there is the capacity to make huge changes to how existing components are produced, as well as creating completely new materials, with applications from semiconductor electronics to medicine. Nanotechnology stands to benefit from 3D printing as it allows the materials and devices to be assembled without a human operator. This would speed up previously lengthy tasks, produce less waste, because it is automated these processes can become economically viable. This viability is the key to taking these technologies out of the lab and into places where they can make a real difference.[15]

One example of a 3D printing being used as a nanotechnology is a process known as two-photon lithography. This is similar to traditional stereo-lithography but the laser-cured resin can absorb two photons at once. This only happens where the laser has enough intensity, which is right at the center, and therefore allows much greater precision in the curing process. The technique can achieve resolutions of less than 50 nm, allowing structures such as castles to be built on the head of a pencil. A Vienna based team hopes to use this technique along with a biocompatible resin to make support scaffolds for living cells.

It isn’t just the medical field that is making use of 3D printing and nanotechnology; it can be used for developing new, high strength materials for building as well. A team out Virginia Tech in the United States is engineering nanoscale features into 3D printed materials that give existing materials previously impossible mechanical properties such as minimal weight and maximum strength. They design the materials from the nano through to the micro to the macroscale so that the properties may be retained and made use of. These properties can be strength, hardness, or even an increase in the tensile elasticity, all of which may be of use to the aerospace and defense sectors.

These are just two small examples of where 3D printing is being used to create nano-sized structures or features in materials. 3D printing offers a great improvement in the speed at which these materials can be produced, which has been a significant hurdle to their more widespread introduction. With interest continuing to grow into this field, technologies such as these may be closer than previously thought.

Nanotechnology and 3D-Printing

Additive manufacturing is a way of making 3-D objects by building up material, layer upon layer, with the guidance of a digital design. The processes are engineered to use material more efficiently, give designs more flexibility and produce objects more precisely. Above all, they make things quickly.

3-D printing was developed by a Massachusetts Institute of Technology team led by Emanuel Sachs in the late 1980s (patent 5204055).[1,16] Also known as binder jetting, the technique involves laying down a layer of a powder and then squirting a liquid binder on the areas to be solidified. While similar to conventional ink jet printers, 3-D printers are able to build additional layers on top of previous ones to construct 3-D objects, even sophisticated objects that serve as medical implants.

These 3D printing techniques are reaching a stage where desired products and structures can be made independent of the complexity of their shapes even bioprinting tissue is now in the realm of the possible.

Already, 3D printing can now be used to print lithium-ion microbatteries the size of a grain of sand. To make the microbatteries, a team based at Harvard University and the University of Illinois at Urbana-Champaign printed precisely interlaced stacks of tiny battery electrodes, each less than the width of a human hair.

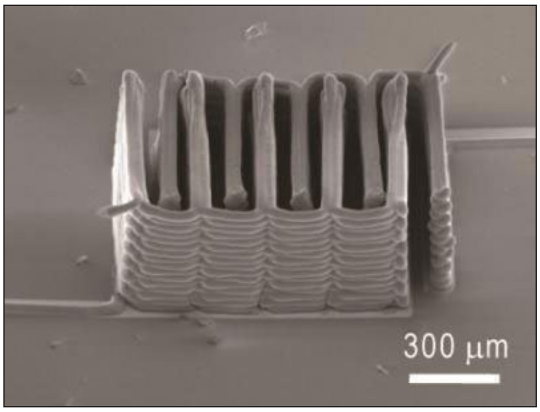

Figure 2.This Image Shows the Interlaced Stack of Electrodes that Were Printed Layer by Layer to Create the Working Anode and Cathode of a Microbattery. (Image: Wyss Institute for Biologically Inspired Engineering at Harvard)

Applying 3D printing concepts to nanotechnology could bring similar advantages to nanomanufacturing speed, less waste, economic viability than is expected to bring to manufacturing technologies.[17]

For example, printing three-dimensional objects with incredibly fine details is already possible using a direct laser writing method called two-photon lithography. With this technology, tiny structures on a nanometer scale can be manufactured, such as the race car, which is only 285 µm long.

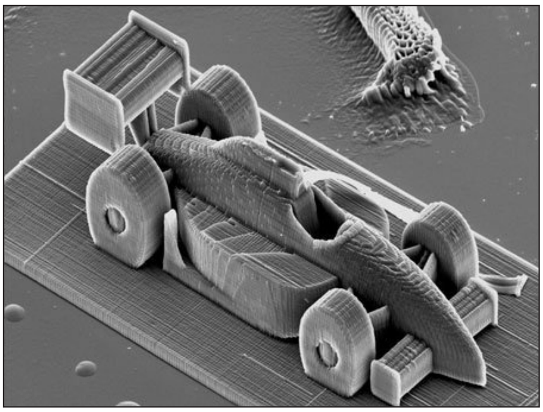

Figure 3.A 285 µm Long Race Car, 3D-Printed at the Vienna University of Technology. (Image: Vienna University Of Technology)

The entire process can be seen in this video: a race car with dimensions of 330x130x100 µm3 is manufactured. The structure consists of 100 layers, each of which consists of an average of 200 polymer lines. It is finished in 4 minutes and resembles a CAD file with a precision of ±1 µm:[5-6]

Another example of two-photon lithography is the manufacture of elaborate micro-and nanostructures of fractal truss such as the one below. Here is a pattern in a polymer that allows the laser beam to crosslink and harden the polymer wherever it is focused. Unlike a 3D-printing-only process, however, this technique requires additional steps, such as coating the scaffold and etching out unused polymer.

3D printing has historically been mainly used to create replicas of natural and man-madeobjects like biological implants, toys, art statues, metal structures, etc. But here it is interesting: with advanced 3D printing techniques, complex micro and even nano structuresthat are not feasible by other manufacturing techniques can be made. For instance, it is almost impossible to shape brittle ceramics into 3D structures with current cutting techniques that could have a major impact on compact sensor concepts, tunable acoustic arrays and powerful power scavengers.In order to address the issue, UC San Diego researchers have recently shown a new tool that uses piezoelectric nanoparticles in a photoreliable solution for the manufacture of 3D piezoelectric materials.[18]

The application of 3D printing techniques enables the creation of evolved structures such as shark skin, lotus effect, bio-inspired sensors.

Macroscopic materials typically contain multiple breaks, voids or other building defects that cause the material to fail much less than anticipated at loads. On the other hand, their nanoscopic equivalents are practically defective and are thus capable of resisting increased loads. Integrating the mechanical characteristics of nanoparticles into macro-scalable materials will offer a new niche in a wide variety of applications, for example in the aviation industry. Nanoparticles are nevertheless still a significant challenge to be assembled into stable macro structures.[12]

By 3D-printing, researchers have been able to assemble nanoparticles into solid macrostructures. The method is carried out with specially built direct-writing benchtop systems first developed by the team of Professor John Hart, MIT, and further implemented in TUHH. 'Interestingly, 3D printed material strength lies within the spectrometer of values recorded for the brick and mortar hierarchical composite materials known for their exceptional mechanical properties.[8] The team printed standalone millimeter columns that comprised the organized arrangement of the spherical iron oxide nanoparticles (supercrystals) (15 nm diameter). The most important characteristic of these nanoparticles is their surface coated with short organic molecules (oleic acid). Indeed, the extraordinary mechanic properties finally achieved are responsible for this surface functionalisation. Next, it allows nanoparticles to be assembled closely in packaged orders (the so-called supercrystals). Secondly, organic molecules serve as active sites for further enhancement of materials. This reinforcement takes place through heat therapy in inertia and establishes new connections between the organic molecules of adjacent nanoparticles through a process called cross-linking. The cross-linking strengthens the organic component, which becomes resistant to higher loads, in keeping with the curing process of epoxy resins.[10] "Three-dimensional printing is a fast and controllable way to produce new materials, previously 3D printed particle-based materials were typically poor because their particles were mainly kept together by weak forces (like van der Waals). In our case, the cross-linking phase serves as a reinforcing mechanism.In a long term perspective, the authors envisage that this combination of 3-dimensional printing and self-assembly would pave the way for integration of nanoscale building blocks with a variety of multifunctional macroscopic materials that range from photonic devices to new structural materials.[9]

Conclusion

This article scratches only the surface of printed nanotechnology, a fascinating and complex topic and luckily invites you to delve into two of our time's most exciting and promising developments. The 3D bioprinting technique for patient specific tissue scaffolding is one of the attractive biofabrication techniques used for different applications in tissue technology and renewable medicine. Nanotechnology may create different types of nano-engineered material and materials for strengthening, which can manage the microenvironment of cells and help grow and work culturally-specific cells for each application. Large studies show that the functional properties of cells and stem cells in engineering tissues or organs can be regulated or managed with nanotex scaffolds. Nanotechnology therefore provides the possibility of producing new scaffolds, combined with 3D bioprinting, that can modulate cell or stem cell destinies and functions. While numerous technological progress has been made with 3D bioprinting, the interaction between the nanoscale microenvironment and cells or stem cells, which is important for the production of physiologically functional tissues and organs, is relatively little known about nanomaterial-based scaffolding 3D bioprinted for applications of tissue engineering. 3D bioprinting is also in its infancy for nanomaterials.

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