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APPLICATION OF NANOTECHNOLOGY IN THE MANUFACTURING SECTOR: A REVIEW

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Abstract
This review of the manufacturing processes in the evolving field of nanotechnology describes the production of nanomaterials by the modification of conventional production techniques. A number of the manufacturing techniques for nanomaterials production and the challenges in the adaptation of the processes to enable nano production are highlighted. Examples of practical applications of nano-structures, materials and components are given. The challenges and risks their applications pose to the wider society are discussed. Suggestions are made on how the social and ethical implications of nanotechnology can best be addressed. A proposition on the way forward for nano production and the integration of their products in the society is also discussed. The challenges and prospects in nano-manufacturing are presented.

Keywords: nanotechnology, nano-materials, nano-manufacturing, nano-production, production engineering

1. Introduction
Global economic pressures as a catalyst for energy conservation and optimal utilization of resources continuously challenge the engineering profession, particularly production engineering, to seek for increasingly sophisticated devices and structures with novel properties, and products of decreasing component sizes thereby fulfilling the objective of achieving less material usages and hence less energy consumption. Nano materials production is a response to this global trend. The achievement of that goal through nano materials manufacture can only be found in the development of state of the art manufacturing techniques that drive nano-size production. Nanoscale manufacturing refers to the production of structures, materials and components with at least one lateral dimension between 1 nm and 100 nm including surface and subsurface patterns, 3D nano structures, nano-wires, nano-tubes and nano-particles [1]. Potential benefits result from miniaturization (e.g., sensors) and from the unique properties of the materials (e.g., high strength). A logical step in the drive to meet the demand for product miniaturization and nano-material and structures enabled novel functionality is to achieve the desired nano precision and resolution through the development and wide implementation of nanofabrication technologies [2,3]. Nanotechnology offers the possibility of introducing technologies that are more efficient and environmentally sound than those used today.

The main methods for the production of nanoparticles can be grouped into three [4,5]: (i) physicochemical methods e.g. the creation of nanoparticles using preformed polymers and inducing their precipitation by emulsification–solvent evaporation, diffusion or reverse salting-out, (ii) in situ chemical synthesis methods of macromolecules, giving rise for instance to polymerization or interfacial poly-condensation reactions [6], (iii) mechanical methods e.g. use of high-energy devices like high pressure homogenizers, sonifiers [4], or high-energy wet mills [7]. The focus here is primarily on the mechanical method because it has provided cost-effective techniques that have made their way into several scientific areas, such as biomedicine, filtration, electronics, sensors, catalysis and composites [8,9], and fabrication involving materials like metals [10,11,12], non-metals like semiconductors [10,13], magnetic multilayered nanowires [14], glasses, nanotubules [10].
This paper reviews advances in the development of nano-manufacturing technologies in order to highlight the state of the art and challenges. Their industrial applications and scientific/ technological challenges are also discussed.

2.0 Methods of nanomaterials production
The following methods are used for the production of nanomaterials:

2.1 Electrospinning technology for nano fibre production

Nano fibres production has been achieved by use of the electrospinning technology to produce three dimensional, ultra-fine fibres with diameters in the range of a few nanometers (more typically 100 nm to 1 micron) and lengths up to kilometers. These nano fibres present unique properties such as extraordinarily high surface area per unit mass, very high porosity, tunable pore size, tunable surface properties, layer thinness, high permeability, low basic weight, ability to retain electrostatic charges and cost effectiveness among of others[15].

Being a continuous process, electro spinning disposes itself to high volume production of nano fibres. The orientation of fibres which is crucial for different applications of nano fibres is obtained through set-ups during manufacture. Rotating collection devices are the most common set-ups. One technique is dry rotary electro spinning which involves the organizational alignment of electro spun nano-fibres in planer assembly [16]. Another technique is a scanned electro spinning nano fibre deposition system. This method achieves uniform fibre deposition and produces self-assembled composite fibres of micro- and nano particles aligned in a polymetric fibre.

One primary advantage of electro spinning is that it can be customized to produce nano fibres to meet the requirements of specific applications. Carbon and ceramic nano fibres made of polymeric precursors further expand the list of possible uses of electro spinning nano fibres [17]. This production process has impacted several scientific areas such as biomedicine, filtration, electronics, sensors, catalysis and composites [9, 18,].

Electro spinning has proven to be a very simple and versatile method of producing and handling a wide range of materials that can be spun. This top down micro/ nano production method is of relatively low cost compared to that of most bottom-up methods; it is also environmentally friendly because it consumes only a small amount of electrical energy [19].

2.2 Nano particles by spraying

Spraying drying has been found to be a suitable method that offers the advantage of drying and particle formation in a single step continuous and scalable process with general engineering possibilities [20]. Typically various particle properties such as particle size, bulk density and flow properties can be easily tuned through simple manipulation of process parameters or spray drier configuration [21]. Spray drying comprises atomization of feed into spray, spray-air contact, drying of spray and separation of dried product from the drying air [20].

The Nano Spray Dryer B-90 (Buchi company) (Figure 1) utilizes a vibrating mesh technology for fine droplets generation. It consists of a piezo-electric driven crystal spray head (Figure 2) which is incorporated with a spray cap that contains a thin perforated membrane (spray mesh) having an array of precise micron-sized holes. Driving the piezo-electric actuator at ultra-sonic frequency causes the mesh to vibrate up and down thereby injecting millions of precisely sized droplets through the holes generating aerosols [21]. This equipment operates on a laminar fluid flow principle, in which the laminar flow is generated by air passing through compact porous metal foam that is conducive for optimal energy input and has short heating up rates. Laminar flow lends itself to gentle heating which makes the system ideal for heat sensitive biopharmaceutical products. Its vertical spray dryer configuration facilitates direct and straight down collection of particles into the collector, which helps to minimize particle adherence to the side of the walls of the glass chamber, thereby allowing for much higher collection yields.

The application of nano-particles which is favoured over micro-particles in drug delivery due to their small size and higher specific area which favourably results in much improved distribution rates and bioavailability [22] has driven their inclusion in many formulations by pharmaceutical companies and generated interest in the development of matching production techniques.

2.3 Template synthesis- membrane based technology for generation of nano/micro materials

The basic principles of templates synthesis is similar to that of producing components through the use of replication for example like making ice candies out of moulds [23]. This technique involves the deposition of materials within the pores of the membranes by either electrochemical or chemical (electroless) reduction of the appropriate metal ion. The structures produced are either homogeneous or heterogeneous. Several researchers have used this technique and its refinements in the fabrication of thin wires as small as 20 nm using mica with etched pores as templates for the growth of such elements of the microstructures [24, 25, 26].

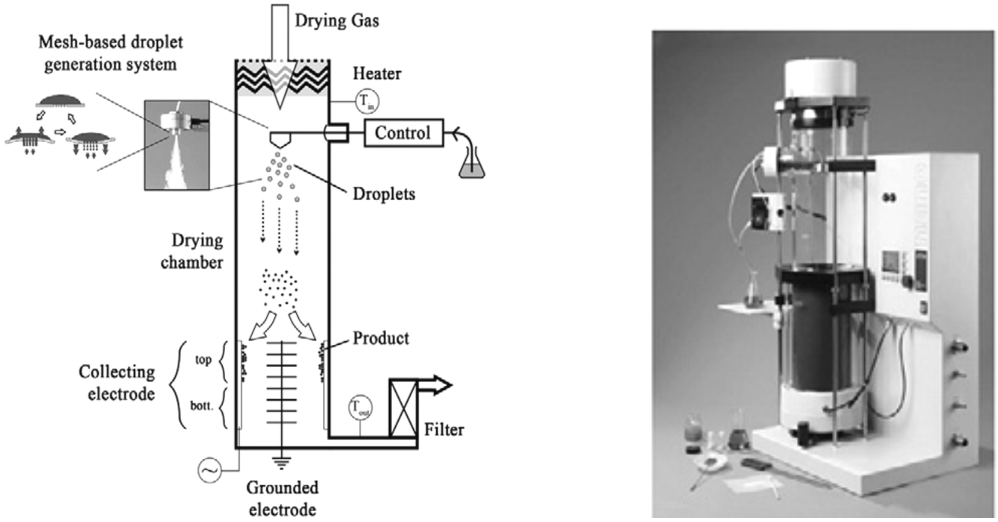

Figure.1: Nano Spray Dryer B-90 (Buchi company) utilizes a vibrating mesh technology for fine droplets generation.

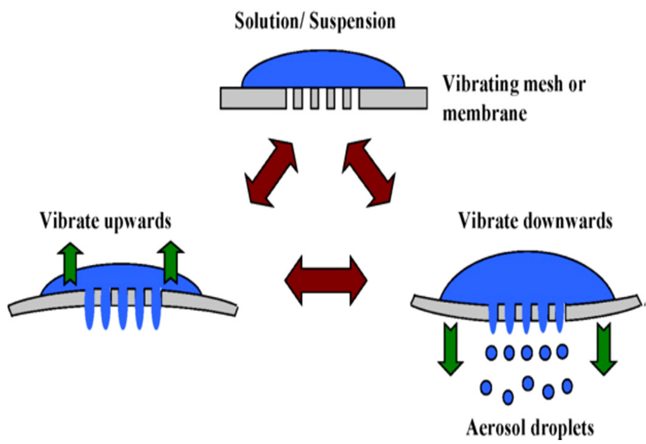

Figure.2: *The functional principle of mesh vibration occuring at the piezo-electric driven spray head of the Nano Spray Dryer B-90, adapted by permission from BÜCHI Labortechnik AG , Flawil, Switzerland.*

The template synthesis of semi-conductors is usually accomplished through galvanic replication technique by permitting the synthesis process on a metallic substrate so as to produce metal – semiconductor structures. Template synthesis of polymeric fibril is based on the consideration that enhanced electronic conductive are obtained if polymers with enhanced molecular order and super molecular order having ordered polymer chains through stretching, crystallization or both can be prepared.

2.4 Laser nano manufacturing

Laser materials processing finds applications in cutting, welding, drilling, cleaning, additive manufacturing, surface modification and micro-machining. It is known that in most cases, the feature size and the resolution of machining are above 1 μm. One of the reasons for the limited resolution is the diffraction limit of the laser beams in the far field (where the target surface from the optical element is greater than the optical wavelength) governed by [1]:

$$d = \frac{\lambda}{2n\sin\alpha} \qquad (1)$$

Where d is the minimum beam spot diameter, λ is the laser wavelength; n is the refractive index of the medium of beam delivery to the target material and α is beam divergence angle.

The best theoretical resolution is known to be around half the laser wavelength. The challenge is to achieve a nano-scale ($\leq$100 nm) resolution in direct laser fabrication of surface structures. This challenge is addressed through the use of high numerical aperture optics and shorter wavelength light sources e.g. deep ultra-violet laser sources have produced lines of 130 nm and lithography (32 nm and 45 nm with optics immersed in a high refractive index liquid) [1]. Applications for achieving smaller surface patterning feature sizes are costly, low power output and unstable in light intensity.

Near field optics utilizing evanescent waves at close proximity (within the length of the light wavelength) from the focusing optics have been recently applied for laser based nano-fabrications beyond the diffraction limits. In addition, femto second pulsed lasers have been used to achieve far field nano-resolution fabrication based on ablation threshold setting of the Gaussian beam profile of the lasers and non-linear light absorption effects. Laser radiation on scanning probe tips for nano-fabrication has been reported [27].

2.5 A personal nanofactory- a future projection

The above discussion shows that nanotechnology at present is involved largely in the production of nanomaterials by the modification of conventional production tools and utilization of the nanomaterials for diverse purposes. It is envisaged that in not too distant future there will be advancement leading to the development of nanopersonal factory. This is conceived as portable equipment that can rest on an office table. This is achievable with a working fabricator, a nanoscale device that can combine individual molecules into useful shapes. A fabricator could build a very small nanofactory, which then could build another one twice as big, and so on.

It is conceived that products made by a personal nanofactory will be assembled from nanoblocks, which will be fabricated within the nanofactory. Creation of state of the art products will be attainable by use of computer aided design programmes to specify a pattern of predesigned nanoblocks. Such a machine capable of molecular manufacturing has two possible functions: to create more manufacturing capacity by duplicating itself, and to manufacture products. Most products created by molecular manufacturing will not possess any capacity for self-duplication, or indeed for manufacturing of any kind; as a result, each product can be evaluated on its own merits, without worrying about special risks.

3. Societal benefits of nanotechnology

There are immense benefits to the society from the application of nanotechnology. Some examples of the benefits include; More efficient components for the semiconductor industry such as integrated circuits containing transistors produced from carbon nanotubes will be available; Lighter and stronger nanomaterials in bulk quantities to enable more efficient transportation vehicles including automobiles, aircraft, and train systems; It provides unique advantages over other tools, especially when combined with other advanced processing methods, playing an important role in the realization of high density data storage; And the biomedical field has benefited through the laser nano-manufacture of biochips (e.g.,bioelectronic chips and biofluidic chips), microneedles for transdermal drug delivery, ossicular replacement prostheses, tissue engineering scaffolds [28]. The nano-fibrous dressings promote hemostasis, have better absorptivity, semi-permeability and conformability and allow scar-free healing [29]. The nano-fibrous membrane also shows controlled evaporative water loss, excellent oxygen permeability and promotes fluid drainage ability, but it can still inhibit exogenous microorganism invasion because its pores are ultra-fine.

These and many other similar applications are plausible benefits of nanotechnology research, however it should be recognized that progress has cost implications. For example, the creation of a new industry often results in the decline or complete destruction of an older industry. The potential benefits from a new technology must be calculated in a sophisticated manner, taking into account all the life-cycle costs [31]. For example an electric car may reduce some forms of pollution while increasing others such as the release of lead or other dangerous substances into the environment during the manufacture of the electric battery and the disposal of it when the car is eventually junked.

The suggestions on how the social and ethical implications of nanotechnology can best be addressed are captured in the following summary [31];

Nanoscale concepts should be introduced into science and engineering education at all levels, thereby giving the widest possible range of students a fundamental understanding of the field while intellectually linking nanotechnology to many other fields; The training of technologists should include social implications and ethical sensitivity, so their work will be guided by principles that will maximize human benefit; A sufficient number and variety of social and economic scientists should receive effective multidisciplinary training, so they will be well prepared to work in the nanotechnology area; Government agencies, private organizations and industry should support a wide range of high quality theory–based social and economic research studies on nanotechnology, examining both the decision processes that shape the emerging technology and its specific societal impacts once it is deployed; And a knowledge base and institutional infrastructure should be created to evaluate the probable future and intellectual and societal impacts of nanoscience and nanotechnology over the short, medium and long term.

3.1 Challenges of Nano-based manufacturing

Nano based manufacture of materials has advantages in size distribution, material property, geometry, yield and purity. Of interest are laser deposition techniques that allow the generation and growth of nanomaterials at a particular location of a substrate, making it very flexible for device manufacture. Some key challenges in the nano manufacture of materials include enhanced precise size control (including diameter, length and size distribution to within 5 nm), higher production rate, lower cost and novel material properties.

Laser nano-welding as a new technique, is still in the initial stages and requires further investigation [32]. Suitable nano-joining technologies are necessary for future nano-manufacturing process chains. Since many practical engineering materials have grain sizes in micrometres, size effect presents an important aspect to investigate. Fundamental studies would be necessary for understanding how grain structures affect laser nano-surface structuring.

3.2 Environmental, Safety and Health Risks

The extremely small size and relatively large surface areas of nano materials may result in their interacting with the environment in ways that differ from the more conventional materials. Potentially harmful effects of nanotechnology could result from the nature of the nanoparticles themselves and from the products made with them. Environmental, safety and health risks could occur during the research, development, production, use and end-of-life processes. Some research has been conducted on the toxicology of nanomaterials but research on the fate, transport, and transformation, risk characterization, mitigation and communication, and exposure, bioaccumulation, and personal protection has yet to come [33].

Apart from the fact that there are relatively few studies on the environmental, safety and health risks of engineered nanoparticles, there are also no regulatory requirements to conduct such studies, and little funding is allocated to them in countries where the technology is being researched. The limited results to date are neither conclusive nor consistent; for example, evidence indicates that nanoparticles in the lungs may cause more severe damage than conventional toxic dusts, but few if any inhalation or exposure studies have been conducted [34].

The deployment of nanotechnology may enhance clean up of soil and water contamination, but the process may harm the local soil ecology. The impacts of large quantities of nanoparticles on the environment or human health have not been studied, and there are no studies on the accumulation or other long term impacts [33].

4. Conclusion

The challenge today and in the future is to develop efficient and economically viable manufacturing/ fabrication processes in nano-technology that assure nanomaterials are available in sufficient quantity and at affordable cost for utilization in diverse applications. The fact is that many of the processes, such as laser manufacturing of surface nano-structures, are still in the basic research phase. The commercial applications of laser nano-manufacturing are growing, particularly in the photonic, electronic, instrumentation and biomedical industries. The development of fully integrated systems (laser, optics, manipulation, software, work piece handling, in-process sensing and control) will boost the practical applications of laser nano-manufacturing.

It is noted too that though spray-dried nanoparticles could be obtained via micro-mixing coupled with conventional spray drying approaches, the Nano Spray Dryer B-90 offers a novel one-step solution-based alternative at much higher yields. The particle size and morphology of the nanoparticles were largely regulated by the spray mesh size and surfactant concentration, respectively.

The electro spinning method is environmentally friendly because it consumes only a small amount of electrical energy it also provides nano-fiber structures that imply a large reduction in material consumption.

The goal of this review has been to provide basic information on the manufacturing techniques in this emerging field that are poised to revolutionize science and engineering and medicine in the near future.

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