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# 나노트로닉스-나노테크놀로지에서 엔지니어의 역할

# Nanotronics-The Role of the Engineer in Nano-Technology.

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## ABSTRACT

The role of the Engineer in the era of nano-technology is explored, a trend in manufacture which is expected to yield a $20-30 billion per annum business throughout the world by the year 2020. The engineers who will be working in this subject will be required to have broadly based experience, over a range of traditional disciplines, such as physics, electronics, software engineering, control and mechanical engineering. As well as having an appreciation of other disciplines such as air conditioning, vibration analysis and its minimisation, the selection of materials for maximum stability and minimal thermal distortion as well as an understanding of ultra precision design and nano tribology.

In other words the engineer who is to be successful in this new and emerging field, will have to be broader based than engineers of the past, where it was traditional to break up the elements of a discipline to smaller subsets. But as nano-technology advances and the subject brings about the evolution of nanotronics to provide a successful solution to emerging problems, it will be essential for a breed of engineers to develop who can consider the subject in a holistic manner.

This paper therefore considers the emergence of nano-technology, predicts the subsets of the development and places them in context of the new engineer which will be required in increasing numbers. The paper summarises the skills of the proposed nanotronics engineer and provides a basis for their training and development.

**Key Words** : Nano-technology(나노기술), Precision Engineering (정밀공학), New Technologies (신기술), Nano-precision (나노정밀도), Nanotronics (나노전자공학).

## 1.0 Introduction.

Precision engineering has been a term used to express the best of engineering manufacturing capability for more than two hundred years, but the interpretation of what is meant by the term has been continually refined. During the middle half of the eighteenth century, two hundred and fifty years ago this term was first used in horology to describe the work of the precision clock

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makers. John 'Longitude' Harrison (1693-1776) who was trained a carpenter, and became a clock maker who was noted for the development and the production of precision clocks (Refs. 1 & 2.). As the years passed, precision manufacture was introduced and refined to enable the batch production of guns, a subject until then was confined to the art of individual manufacture by craftsmen of the age, who skilfully made and fitted the various parts to produce 'bespoke' weapons, in the main gentleman's weapons, which were used for sport and sometimes warfare. As the twentieth century progressed new machines were developed and processes refined to allow precision engineering to progress to what is understood by the word today Ref. 3.). The progress of precision since its inception is summarised in figure 1.

Mechanical technology is the key to nano-technology, for it is through the application of very precise mechanical technology, backed up by other disciplines, that precision part integration is ultimately possible. The mechanical engineer who is going to be successful as part of this new

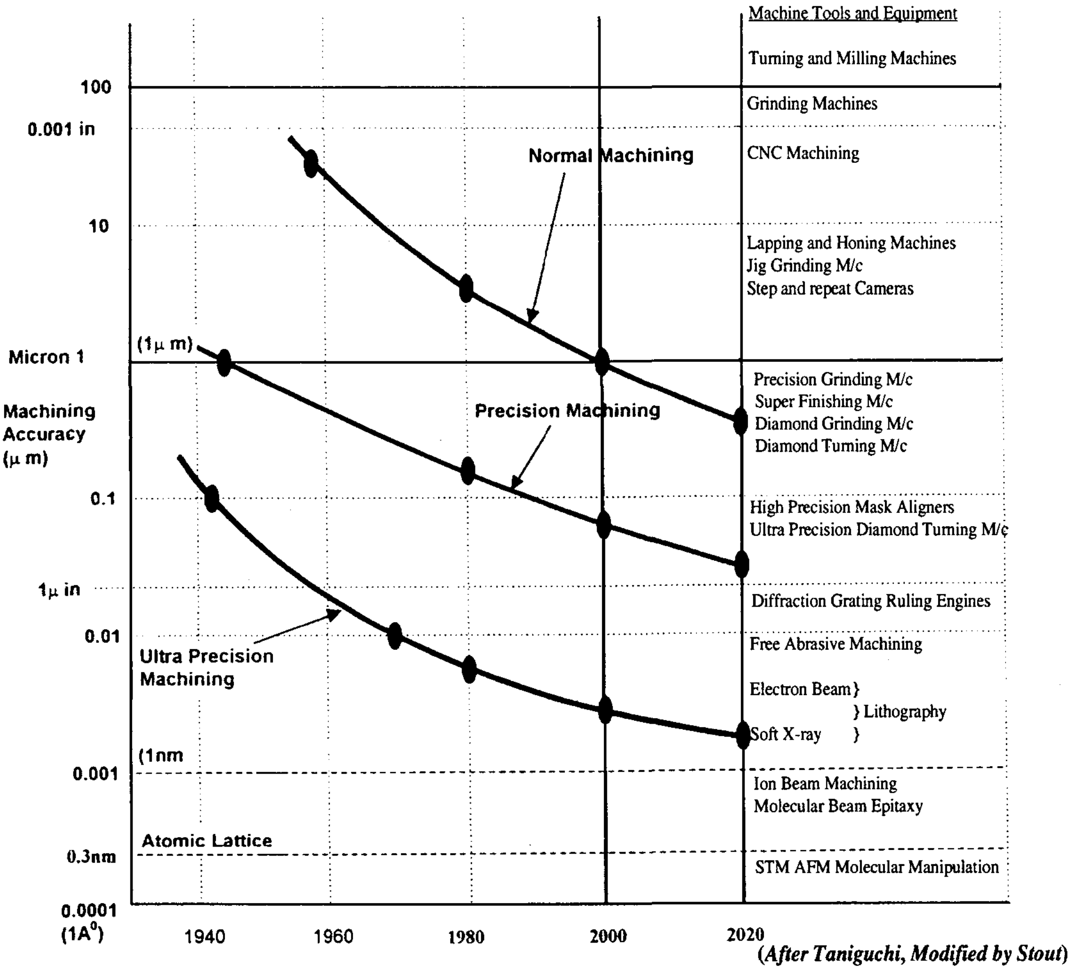



**Fig. 1 Progression of Precision Manufacture**

and exciting, emerging technology (one in which the defined working range is 0.1 micron $[10^{-7}m]$ to an angstrom$[10^{-10}m]$ must have a firm understanding of many of the related disciplines. Examples of the current technologies which span the nano range are shown in table 1. These technologies involve precision manufacture, electronic control systems, precision measurement and the understanding in a general way of optical systems, materials and their capability. All of these technologies will appear at some stage in the mechanical design of devices, instruments and machines used in nano-technology.

The scope of the future engineer, who is expected to be involved in nano-technology may be a surprise to the reader. But it is important to recognise that although many of the final nano-technology products will be solid state devices, much of the means of producing such devices will be through the appropriate integration of a range of technologies involving mechanical technology as their base. It is not only important that the engineers involved in these developments have a firm mechanical base but they must be sufficiently well developed that they can understand the scope of the engineering dimension within which they will be immersed.

**Table 1. The Metre Scale and its Derivatives.**

| SCALE | | PRODUCTS | |
|---|---|---|---|
| $10^{-2}$ | | | |
| | | Length of a football pitch. | |
| $10^{-1}$ | | | |
| | | Building blocks of the pyramids. | |
| $10^{0}$ | metre. | | |
| | | The width of a house brick. | |
| $10^{-1}$ | | | |
| | | Typical diameter of a hydrostatic bearing orifice. | |
| $10^{-2}$ | centimetre. | | |
| | | The dimension of a Pentium chip. | |
| $10^{-3}$ | millimetre. | | |
| | | Typical engineering tolerance of quality parts (1940-1990). | |
| $10^{-4}$ | | | |
| | | Typical diameter of an air bearing orifice. | |
| $10^{-5}$ | | | |
| | | Typical size of a bacteria. | |
| $10^{-6}$ | micron. | | |
| | | Line width of production VLSI (1985). | |
| $10^{-7}$ | | | |
| | | Minimum gate size of a pentium chip. | |
| $10^{-8}$ | | | Nano-technology |
| | | Best surface finish of single point diamond machining. | |
| $10^{9}$ | nanometre. | | |
| | | Atomic diameters. | |
| $10^{-10}$ | angstrom | | |
| | | Resolution of Xray interferometry. | |
| $10^{-12}$ | pica-metre | | |
| | | The size of the larger nuclei | |
| $10^{-15}$ | femto-metre | | |
| | | The size of the smaller nuclei | |
| $10^{-18}$ | atto-metre | | |

## 2.0 The Role of The Nanotronics Engineer.

Let us now consider the general role of the nano-technology engineer who will be immersed in nanotronics. Clearly as indicated above they require a broad knowledge of a wide range of precision engineering disciplines, as well as the technologies associated with the education of electronic and optical engineers. The nano-technology engineer must therefore be intelligent and well educated and it seems appropriate that the new generation is trained to a first degree level qualification. A first degree level qualification alone, although significantly important in itself, is not sufficients the nano-technology engineer needs to be directly immersed in the subject. The value of 'hands-on' industrial training cannot be underestimated. This is where the engineers have the personal opportunity to learn how to manufacture parts and fabricate assemblies and in the process, to experience the relative difficulties of the craft skills that are part of this intricate manufacture.

Nano-technology will develop quickly to become a $20-30 billion business a year worldwide(ref. 4.). As a consequence of this rapid development many engineers will be sought, to enter and contribute to this emerging technology. The field is so comprehensive that it seems appropriate that experiential training will be the most useful manner in which to develop the young engineers.

A way forward in the development of the nano-technologist, is to include in their formal education to first degree level, an industrial training year. This training period would embrace many subjects if the undergraduate trainees could be seconded to ultra precision engineering training centres. Such centres, with financial help, could be set in strategic sites in the UK and Europe. It is almost certain that appropriate sites will be set up in South East Asia. An alternative training scenario would be to immerse the undergraduates in high technology, high precision companies where they could be exposed to a range of experiences in the company which relate to the emerging technology.

## 3.0 Possibilities for Training of Future Nano Engineers.

The best practice in this type of training, one which is already in regular operation for all students studying engineering at the University of Huddersfield in the UK, is the 2.1.1. course where students undertake their training for the whole of the third year of the undergraduate programme. Each student is assigned to an appropriate company where the scope of training provided is selected to compliment many aspects of the course of study in which they are engaged.

The nature of the type of 'hands on' training which would be appropriate for the nanotronics engineer would necessarily need to embrace a number of skills and techniques that were relevant to the subject of nanotechnology. This involvement would be either through manufacturing products which employ the technology or machines, systems and instrumentation that provide the capability to make such products. In the UK for example such companies embrace many disciplines. IBM, in their Havant and Hursley plants are involved in electronic device manufacture, prototyping and machine requisition as well as software development. Renishaw a precision metrology company at Wootton-Under-Edge undertake a range of activities into the design of precision instruments, demonstrating competency in a range of skills. A third example is that of the Reliance Gear Company of Huddersfield who make a range of precision products for world wide distribution and employ as a consequence a range of nano-machining skills, in addition they operate the necessary instrumentation and measurement skills to support the manufacture.

These are only three out of more than one hundred companies who's products and activities demand the nano-technologist skills. Many of their products are completely dissimilar to the other companies in the field and as a consequence their activities are varied. What is common to all the companies is they are heavily engaged in many aspects of nano-precision and therefore require the possession of specialist skills in their employees to enable them to play a major role in developing their company's manufacturing capability. They, and their counterparts throughout the world, require the appropriate skills embedded in their employees. These skills are required at the graduate level as production and design engineers and at the craft level as skilled tradesmen, who are able to produce products of the required precision and quality to meet the growing needs of the emerging technology.

These companies throughout the world employ both males and females, the majority working on clean manufacturing processes in clean or ultra clean environments. Very often these environments are high quality clean rooms which are necessary to ensure the integrity of the manufacturing process.

Quite clearly the undergraduate will be subjected to a number of aspects of ultra precision engineering, and will as a consequence become immersed in a number of techniques and skills which will benefit them in their later careers.

## 4.0 Academic Background for Nano-Technology.

It is useful to consider what backgrounds are appropriate to nano-technology. Traditionally people have entered the field from a range of disciplines which include physics, chemistry, electronic engineering, materials engineering and mechanical engineering and indeed all these areas are still appropriate to the subject. But as the discipline grows, additional backgrounds are being required and these include manufacturing engineers as the volumes of products produced by this technology increases, software and communications engineers, optics, refrigeration and air conditioning engineers and finally machine and facilities designers.

What is more important is that many specific skills, which have been acquired during progress through undergraduate courses, are the subsidiary skills which are considered of paramount importance in modern industry. These include communication skills, group working experience, human interaction, lateral thinking, energy and determination. All attributes that employers currently strive for in their appointments. Employers will be critically examining for these attributes in the nano-technology recruitment situation.

## 5.0 Mechanical Technologies and their Scope.

This paper is primarily directed at the mechanical technologies which underpin nano-technologies and there are many which have a great influence on them. Table 2. below attempts to list many of the disciplines which are of importance. For example bearing design (magnetic, aerostatic, precision ball and roller) are often used in such applications, Each one of these solutions has its own advantages and disadvantages, each one has its place in the technology. Where none of these

**Table 2. Nano-Technology Disciplines.**

Nano-Technology

| Engineering | Physics | Chemistry | Medicine | Pharmacy |
|---|---|---|---|---|
| Machining, | Optics, | Chemicals, | Biology, | Pills |
| Fabrication, | Electro-Optics, | Electro-Chemistry, | Surgery, | Auto-dispense |
| Assembly, | Material Growth, | Machining, | Implants, | Particles |
| Electronics, | Manipulation, | Purity, | Intelligent Implants | Powders, |
| Mechanics, | Molecular Processing, | Lithography, | Biological Computers, | Intelligence, |
| Machine Tools, | Composites, | | Genetics, | |
| Actuation, | Ceramics, | | | |
| Structures, | | | | |
| Energy Beam Processes, | | | | |
| Quality, | | | | |

fit the requirements due to problems of hysteresis, then flexures, solid hinges can be successfully applied. These can be moved with great precision, although they are sometimes accompanied by very small amounts of 'cross-torque' between the directions of relative movement. Careful design can eliminate or minimise the effects of 'cross-torque'. In the fields of ultra precision engineering or nano-technology, hysteresis or backlash is an aspect of operation which requires elimination. This description is one of many which could be highlighted to demonstrate the significance of mechanical design on nano-technology but it must be remembered that it is not only the primary technology which it is important, but the integration of that technology with controls and analysis, to create the comprehensive product which are required. It will now be useful to identify a range of disciplines which are important in the study of nano-technology.

## 6.0 Areas of Study Appropriate to the Nano-Technologist.

### 6.1 Transducers.

The transducers which are associated with data collection and positional control are of significant importance and offer much scope for improvement as nano-technology develops. Optical transducers, such as those employing solid state laser diodes have been successful but greater demands are being placed on these devices to perform to higher resolution. Table 3. presents some information on the improvement of resolution which has be a function of the increased applications of these devices. A new development is the realisation of a blue diode laser that could eventually lead to laser printers with between two and four times the resolution of today's 60 dots per mm machines. This breakthrough will, for the first time, permit computerised laser printing to match the quality of the world's finest traditional printing machines. These laser will also find their way into markets such as audio, video and computer data storage. Recently there has been acknowledgement that capacitive transducers have not reached there full potential and can be used in the nano-technology range. These devices will provide a cheap solution in future to some of the gauging problems. As a consequence they are growing in popularity in the nano-technology field.

**Table 3. The Recent Evolution of Laser Resolution.**

| Laser Type | Vacuum | Air |
|---|---|---|
| Laser Diode 1990 or the order of | $1\times10^{-7}m$ | $1\times10^{-6}m$ |
| Laser Diode 1997 Renishaw Publication | $1\times10^{-8}m$ | $1\times10^{-7}m$ |
| Gas Laser | $1\times10^{-10}m$ | $1\times10^{-9}m$ |
| Blue Laser 1997 | $1\times10^{-12}m$ | $1\times10^{-11}m$ |

## 6.2 Design of Machine Elements.

In nano-precision, the elements of machine design, involving the control and the elimination of the effects of temperature gradients is of paramount importance. The changes in ambient temperature and heat sources within the machine have a significant effect on the ability to move or manufacture components to the required accuracy in the region covered by nano-technology. Best practice in ultra-precision machine design is still being evolved, although in recent years many good practices have been introduced into the subject. The selection of the appropriate materials used in machine fabrication is an important factor in the design of high precision machines and many new and stable materials such as Zerodur have been developed and widely employed.

## 6.3 Position Control & Controllers.

This is an extremely important area which is developing very quickly. The use of solid state lasers is a rapidly expanding field and as their performance improves (see table 3.) this has a significant effect on the accuracy and resolution which it is possible to demand from the machines on which they have been fitted. Optical scales for position monitoring have also developed with the production of highly dimensionally stable gratings. These are impervious to the effects of minor temperature variations which can be expected in modern machines. The control of ambient temperature, often enhanced by the application of oil or air showers, which are designed to minimise temperature variations. These temperature variations can be conducted through the machine structure and as a result affect the machine's working tolerance.

Significant developments are now taking place in the design of machine controllers which are steadily becoming more user friendly and have significantly better response times due to the increasing speed and power of modern integrated circuits. As computers become more powerful, such as the modern innovation, the dual voltage gates on the individual switching elements of standard integrated circuits greater storage becomes a reality and doubles their capacity. This development enables more comprehensive programming, without the need for great programme efficiency, a development that will allow the creation of more versatile processors and controllers. Such improvements in the controllers are likely to allow some limited scope for machine 'intelligence' such as the application of expert systems to determine machine error trends and to correct for them.

## 6.4 Construction of Semiconductor Devices.

Semiconductor technology today relies upon silicon, the second most abundant element on this planet as its base material. But after only fifty years of silicon based computer chips, physicists are already thinking about its limitations and as a result they have been actively searching for a suitable successor. At the same time materials scientists have been trying to create a light weight, extremely strong and flexible substance that could be made in abundance, cheaply and would lend itself to use in a broad range of products from a tennis racket to car bumpers and on the more mechanically testing applications such as aircraft frames and in the development of light weight space vehicles and space stations. In the last few years both groups believe that they may have discovered one and it comes from a common material too, soot. A material which has been around ever since primitive man discovered fire, but until recently it has never been thought of as a workable material.

Soot is made from carbon, the most abundant of all materials on Earth and recently physicists have discovered that it has some unique properties, ones only partially realised, and are leading scientists to research further to discover more about them. In 1985, Richard Smalley, Robert Curl and Harold Kroto discovered that when carbon is vaporised in an inert gas such as Helium and then is allowed to cool slowly it spontaneously forms 'buckeyballs', the celebrated American soccer ball shaped carbon molecule consisting of 60 carbon atoms arranged symmetrically.

Buckeyballs are unusual structures. They are chemically inert, incredibly strong and in some cases electrically and thermally conductive. But despite the thousands of research papers devoted to buckeyballs, practical applications remain elusive. As a result of the failures attention has turned to 'buckeytubes' or 'nanotubes' as structures that could be turned into workable structures. Buckeytubes belong to the same family as buckeyballs and they are created by adding millions of extra sets of hexagons of carbon atoms to the middle of the buckeyball molecule so that it stretches out to form a tubular fibre.

For industrial purposes the buckeytubes have always appeared more promising that there spherical cousins. Indeed in the years since the nanotubes were first constructed (1991) researchers have been fascinated by their electronic properties. The latest surprise(1997) is that nanotubes can function as semiconductors. Much of The pioneering work into the semiconductor properties of nanotubes has been conducted at the University of California at Berkeley under the direction of Dr. Zettl. Dr. Zettl and his co-workers employed a scanning tunnelling microscope (STM) to isolate a singe nanotube which is about 20 nanometres in diameter. To achieve this they pushed the tip of the STM onto a substrate covered in nanotubes and then slowly and deliberately withdrew the tip. The result was a complete surprise, as they withdrew the tip a single tube unravelled itself from the tangle of threads and one end remained in contact with the substrate. The researcher were then able to guide the tip across the length of the tube measuring the current at defined intervals (ref. 5.). They found that certain parts of the tube behaved like a metal. They also found that in some parts of the tube that when a voltage was introduced, the current came on only after a particular threshold was reached. This meant the tube reacted in the same was as a semi-conductor.

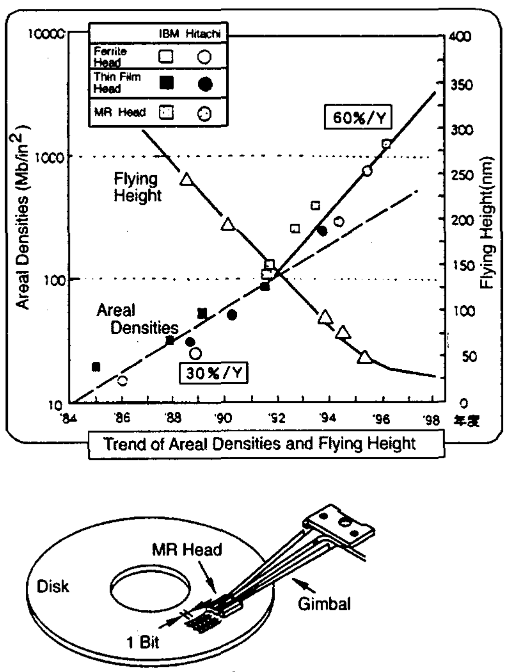
This almost perfect metal semi-conductor junction has a name which is a 'Schottky barrier' and this barrier has been researched through other earlier but less versatile metal semi-conductors. Making a conventional Schottky barrier this small is extremely difficult, atoms inevitably spread out and end up in places that they are not wanted which cause the device to degrade. They also have a tendency to heat up which degrades their performance. The nanotubes do not suffer from this problem because they are all from one homogenous material which does not suffer from these drawbacks. A second breakthrough, reported in Nature (Ref. 6.), suggests that nanotubes are almost impossible to break if they are constructed as 'multi-walled' nano-tubes. The multi-walled nano tubes were subjected to bending and buckling and squeezing yet they survived the mechanical abuse given to them. Clearly there is much development to do before these materials can be sufficiently robust to used in nano-applications but a member of their family, the carbon fibre is finding many applications from aircraft applications to golf club shafts and tennis racquets. Because of their resilience carbon nanotubes may be more effective for a whole range of applications.

There is still much research and development to do before they can be considered to replace silicon as a material since no one can as yet make these tubes reliably with the required properties. But that breakthrough is just a matter of time. It is realistic to assume that in the near future nanotube computers will be developed, also the mechanically resilient nano tubes which have electrical transmission properties may be the answer to the problems associated with nerve severance and trauma in paraplegics, providing an answer to human repair surgery which as yet can only be considered an impossible task. Clearly the research and development which physicists are currently studying, and will soon become the province of the manufacturing and mechanical engineers, may make a major contribution to mankind.

## 7.0 Machining and Fabrication Processes.

The drive towards smaller and smaller devices in terms of computer chips; and the move towards smaller flying heights(figure 2) on disc drive assemblies, currently 10 nano-metre flying heights are being explored in research environments, increases the speed of computing. To support the above technologies, silicon slices require significantly better surface topography control to ensure that the ever smaller connecting wire between gates on the chip retain continuity and meet the pressures of high production rates. As a consequence machining processes used to produce the silicon slices are being placed under ever increasing tolerance restrictions and these place stringent quality control constraints on the finishing processes themselves.

**Developments in Disc Drive Data Transfer-Trends of Areal Densities and Flying Heights**




Head and Disk Configuration

**Fig. 2 Data provided by Hitachi Ltd. Production Engineering Research Laboratories October 1996.**

Diamond turning, grinding, (in particular of steels and glasses, ceramics and other brittle materials) diamond turning, and CBN cutting. Attrition processes such as diamond abrasive lapping and polishing, float polishing have also developed significantly over recent years and are continuing to progress, but much is still to be learned on precision machining.

The supporting technologies such as the evolving high purity etching chemicals and improved lithography techniques to etch the integrated circuits, all support the trend towards more powerful units and higher quality production of the components. There is also the rapidly developing area of fast prototyping of specialist chips which have the ability for easily accepting design error correction. This will assist in the reduction of the cost and time of developing new products. Such improvements are related to the mechanical production of the chips and also to the software techniques which are employed in developing them.

Some of the greatest improvements in nano-fabrication has occurred in the area of etching processes such as chemical machining processes which include the following,- photo and electro lithography, etch machining, electrochemical machining, LIGA deep etching using X rays and electro plating. Other processes currently in use or being developed include reactive ion bean machining which is an etching process, Langmuir Bodgett thin film techniques and molecular beam epitaxy, which is an accretion process.

Clearly these new and exotic fabrication processes are largely in their infancy and are constantly being refined. Once these techniques are developed towards their physical limits the scale of integrated systems will be much smaller than is envisaged today. It is these, and other techniques that will provide the route to the medical solutions alluded to in this paper.

One technique which is already being successfully researched is that of scanning tip engineering. Through the use of scanning tunnelling microscopes and atomic force microscopes employed in a mode to manipulate the atomic structures of materials, researchers are beginning to assemble demonstrator components. This is a very significant area for future product manufacture.

A new process which deserves mention and may well be very important in the future manipulation of materials to be used in nano-technology is the very interesting technique chemolithotropic bacteria processing. Such processes open the door to biological computers and the production of engineered biological devices which may be useful as machines in their own right or employed in nano-medical applications. It is foreseen that through nano-biological devices which have genetically engineered products, the problems of donor organ rejection is likely to be completely overcome.

### 7.1 Nano Design Integration.

This integration is similar to that which is common in normal electro-mechanical devices(mechatronics), the main difference lies in the scale of the technology. As mechatronics is driven smaller, applications for the evolving technologies become possible, ones which currently evade the capability of present day mechatronics. Hence the introduction of the phrase-'nanotronics' in this paper.

Intelligent devices and the developments thereof, inserted into the human body for diagnosis purposes, can play their part in human health maintenance and will play a significant role in improving the quality of life of persons who currently have considerable health problems. These devices have arrived in part already, but a great and significant expansion can be expected in this area. Nanoscale medication, automatically dispensed, nano-constructed titanium wires or nanotubes which can connect severed nerve ends all add to the range of possibilities which can assist health maintenance. Such wires can be used to replace and ultimately repair ruptured nerves and motor controllers inside the human body, which will assist the process of 'repair'. Paraplegics for example may find that they are able to walk again after many years of being confined to a wheel chair. Not only will this greatly assist the damaged person but will yield great savings to the health care community which will mean that the reduced expenditure in this area will provide the opportunity to advance health care in other important areas.

## 7.2 Nano-Mechanisms.

Nano-scale gears which have already been constructed, offer unique advantages in many applications, but also offer some interesting side effects which were generally unexpected. For example friction, which is always a serious consideration in mechanism design, has yielded significantly different properties at the nano-scale where for some so far unexplained reason, the coefficient of friction is considerably less. Clearly the recognised rules of friction do not apply at such a scale of manufacture and hence the physics which was believed to be well understood, requires review in this area of growing importance.

Nano-mechanisms will embrace sub miniature bearings, flexures, nano sized beams and slideways. The use of peitzo electric actuators to achieve minute increments of movement will be further developed. In fact many of the structures that are widely used today, at a larger scale of manufacture, are steadily being reduced, using a variety of manufacturing techniques to meet current demands for precision and miniaturisation.

One of the likely exceptions from the present restraints on manufacture, is that these new generation components and products are likely to be produced with materials which have a higher

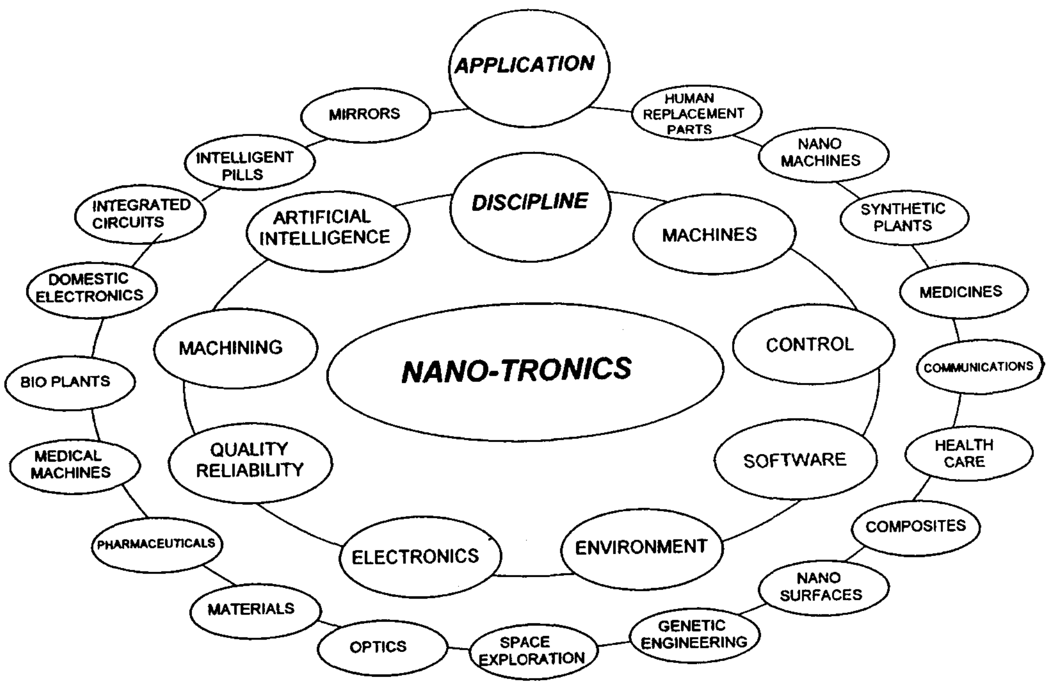



**Fig. 3 The Scope of Nano-Tronics**

degree of purity than is currently enjoyed.

### 7.3 Nano Materials.

This is a further area that offers tremendous scope for advancement. Conventionally materials generally begin as relatively large blocks, then they are 'whittled' away to produce the shapes required. This process has been the basis of all manufacture since the 'flint man' some half a million years ago. Once the final shape of the components have been reached, they are often subjected by some form of heat treatment to adjust they properties. This process is termed 'surface engineering'. A process which is undertaken to modify the surface layers of the whittled material to change their physical properties and make them more suited to the function for which they were intended. In reality these surface engineering processes introduce changes to the structure of the materials often by modifying the basic elements of the materials themseves. Either by removing or adding something to the material's structure. In short conventional methods of producing an artefact is extremely wasteful in terms of materials and energy employed in their transformation, and this process is basically archaic. The majority of the material used to produce the component is lost in the 'whittling' and subsequent processes.

The future technology is logically the reverse of current practice. The future is to construct the required artefact, atom by atom (bottom up), ensuring that during the process, the attached atoms have the specific properties that the finished component requires. In short the future is bottom up construction of both components and products. The whittling process which has been with for half a million years is a 'top down' process. Using this technique it will be possible to fuse complex materials together to yield the functional properties which are required.

The type of materials which will be developed and will become common place, are high purity, high strength, light weight materials which for example will not yield to corrosive effects in severe and hostile environments. The development of synthetic diamonds which can be used as structural materials will also become a broader used reality since their properties will be an advantage in many applications.

## 8.0 Conclusions-Nanotronics and the Future.

Nanotronics is the general term we have introduced for the technologies that make up nano-engineering. For these individual technologies develop and are integrated together, complex devices, having intelligent control, using the latest techniques of artificial intelligence, expert systems and neural networks will undertake a range of tasks which currently are only the dream of science fiction writers. It is difficult to predict the scope of the technologies which will emerge but what is clearly obvious is that they will allow a variety of functions which are currently beyond the scope of modern science and technology. Even beyond the scope of imagination. It is even likely that much of the physics which we all accept as well defined today, may in fact be superseded as the new and emerging technologies develop.

The nano-engineers who enters this exciting field will have a challenging task, one which will steadily lead them into uncharted territory, breaking boundaries which were previously thought impossible. In so doing it is they that will alter the currently excepted bounds of physics. A prediction which before the onset of these challenging technologies, scientists would have considered impossible.

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