Nano-technology Advances Around The World and Its Relevance to the CARICOM Region

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Nano-technology is becoming critically important in various industrial fields, introduces new platforms for wealth creations and offers an abundance of opportunities for improving the standard of living. Significant developments have already taken place to establish the new knowledge of nano-science and manufacturing. This has been achieved using interdisciplinary collaborations. Numerous market reports and forecasting trends predict a rapid growth in commercial products with increased performance, miniaturisation and acceptance. Despite the massive developments in nano-technology around the world, even traces of nano-initiatives are not apparent in the Caribbean community (CARICOM) region. This paper addresses the global developments in nano-technology and their relevance to the CARICOM region. Also, a new interdependent approach is proposed describing the focus and the niche areas.

Keywords: Nano-technology, nano-fabrication, ultra precision.

1. Introduction

In the global scenario, Nano-technology is recognised as the enabling technology towards next generation devices and the industry has already gained enough confidence that this new platform would bring competitive advantages. The worldwide, annual nano-tech-related, industrial production is estimated to exceed $1 trillion in 10-15 years' time and would require about two million nano-technology workers [1]. **Table 1** lists the investments made on this technology by various countries [2, 3].

Using this technology, a wide range of products is being produced. These include cutting tools with wear-resistant coatings, pigments in paints, pharmaceutical - drugs, nano-scale particles /thin films in electronic devices, jewels, optical, semiconductor wafer polishing and many more. Also, no effort is spared in developing biosensors, transducers, detectors, retardant additives, propellants, nozzles, drug delivery devices, nano-power sources, high-end flexible displays, artificial organs and sensors-actuators using the nano-manufacturing process. Successful creation of nano-particles would redimension the product characteristics viz. clay nano-particles have recently made their way in cars and packaging materials [4]. Another example is the use of nano-composites in cars, which could lead to enormous decrease in fuel consumption saving around 1.5 billion litres of gasoline over one-year's vehicle production thereby reducing carbon dioxide emissions by more than 5 billion kilograms [4]. Despite global events, even traces of nano-technology initiatives are not seen in the CARICOM region. This paper examines the potential impact of nano-technology on the CARICOM region

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TABLE 1: *Global Spending on Nano-Technology R&D (US$ Million)*

Region or Country	2000	2001	2002	2003
Western Europe	200	225	400	500
Japan	245	465	650	1000
USA	270	422	604	710
S. Korea	-	70	125	186
China	-	-	50	60
Taiwan	-	36	45	90
Others (Singapore, Canada, Australia, Germany, Eastern Europe)	825	1502	2174	2850

as a whole and proposes a methodology to quickly get into the global corridor of nano-technology, failing which, this region would become a dumping ground for yet another new innovative product.

2. Nano-technology and the Manufacturing Issues

Nano-technology encompasses new ways of making things or devices at nano-scale in 2D and 3D. Prior study emphasised the fact that the micro-fabrication methods adopted for 100 nm size range will not be suitable for 20 nm range. As a result, an entire new set of manufacturing strategies are being developed. Also, materials behave differently from macro scale to nano-scale. Therefore, numerous challenges exist in multi-level design and simulation from process through device, circuit to system. Fundamental behaviours at a nano-scale must be studied using techniques such as high performance computing [5, 6]. Innovations in nano-system simulation and design tools would complement the nano-device characteristics and reduce the lead-time to launch the products. Many nano-engineering features like cantilevers, bridges and cavities cannot be produced using the conventional approach, however, the same can be achieved in combination with physics, chemistry, mechanical and electrical sciences. Processes such as Femto-second ultra-fast pulse laser machining, excimer laser machining, ultra-precision machining, micro-edm, micro-ecm, micro grinding, micro-electro discharge grinding, micro-fluidics, nano-coating, deep reactive ion etching, electron beam lithography have to be deployed for manufacturing the required nano-engineering features [7-16].

The present technological trends in microelectronics enable manufacturers to mass produce engineering features as small as $0.18 \mu m$. However, it is predicted that the minimum feature size will shrink by 70 nm by 2010 [17]. This can be achieved with the comprehensive development of innovative manufacturing processes that define the manufacturing accuracies as shown in **Figure 1** [18].

In context with machining, a new domain "ultra precision machining" was developed that performs complex machining, micro machining and hard-to-machine material machining. Complex ultra- precision machining refers to the fabrication of components with complicated profiles, such as non-axisymmetric and free-form profiles [19-24]. These parts have to be machined on a free form generator (4 or 5 axis ultra-precision machining centre). Only a few universities/institutes in the world (viz, Fraunhofer Institute of Production Technology (IPT) in Aachen, Bremen University, University of Electro-Communication in Japan and Cranfield University in UK, SIMTech, Singapore) have capabilities in complex ultra-precision machining. The fabricated parts include wave beam guides, rod lenses, step mirrors, 1-D phase modulation mirrors, glancing incident mirrors and elliptic cylinder mirrors. A typical mirror with a toroidial profile of 1.2 metres can be fabricated with a PV form accuracy of $0.2 \mu m$ and surface finish of R_a = 3 nm [20-27]. Features of a few micrometres with complicated profiles can be machined with high accuracy and mirror finish. For instance, a human face can be produced in an area of 1 mm diameter [28].

Apart from manufacturing, measurement at nano-metre and sub-nano-metre level is also

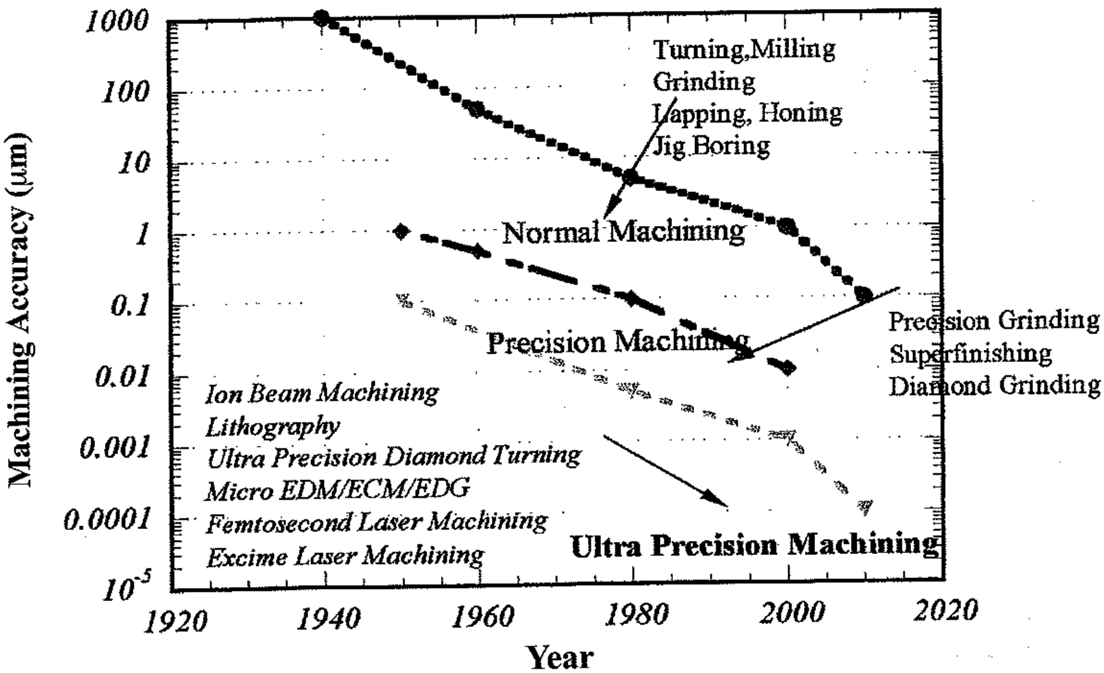


FIGURE 1: *Achievable Machining Accuracies with the Nano-technology Processes*

challenging. New techniques and instruments are being developed particularly combined with optical-x-ray interferometry and near field scanning probe microscopy for measuring and characterising the nano-structures [29-31]

2.1 Nano-technology Advances in Europe

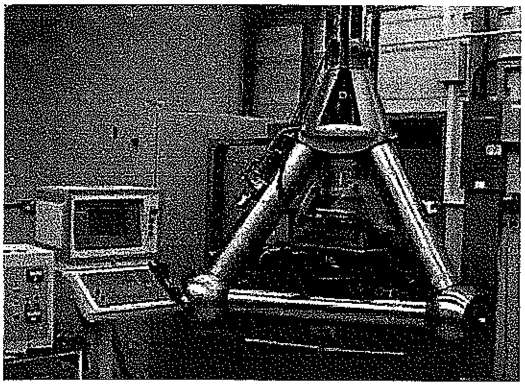
In the UK, Tetraform machines of stiffness >120 $N/\mu m$ and capable of fabricating parts from 10's of centimetres dimensions to sub-100 nm precision were developed by Cranfield precision Engineering to produce mirror-finish surface in steel (see **Figure 2a** and **2b**). This machine is built with an "electrolytic in processing dressing (ELID) feature and enable ductile regime machining even for brittle materials. As a result, a surface finish (R_a) as small as 2.3 nm was achieved [32].

The trend of miniaturisation has reduced the size of electronic-related components to around two to three times in every five to seven years and MEMS (Micro-electro-mechanical systems) technology was developed to produce novel sensors and actuators. Techniques such as deep reactive, ion etching (DRIE) and lithography were applied to produce such parts and presently, these techniques are being extended to Bio-MEMS to produce drug delivery devices, gene therapy and medical sensors. Using the principles of nano-technology, a gyroscope that vibrates in a magnetic or electric field was devised by BAE systems [33]. Also, an uncooled, thermal-imaging, array-based on a ferro-electric, ceramic hybridised onto silicon integrated circuit using flip chip solder bonding was configured. In the nano-measurement region, scanning tunneling microscopes were developed at IBM Zurich that characterise the quantum state of a single atom at the nano-scale. In Europe, the developments in nano-materials have gained significant momentum as they behave very different when nano-structured. A nano-metric range grain size in metals will produce greatly-improved, mechanical properties with yield stress up to three times higher than the normal, micro-structured version [17]. A wide range of nano-particles was tried in suspensions, sol-gel and aerosols and improved performances were clearly seen as the small particles offer larger, active surfaces per unit mass. Commercial applications in paints, UV cream and aerosols were already launched in Europe. **Table 2** consolidates the major nano-developments across Europe [34].

2.2 Nano-technology Advances in Japan

Since 1992, Japan spent a decade in developing the new knowledge in nano-technology, particularly on four major areas:

(A)



(B)

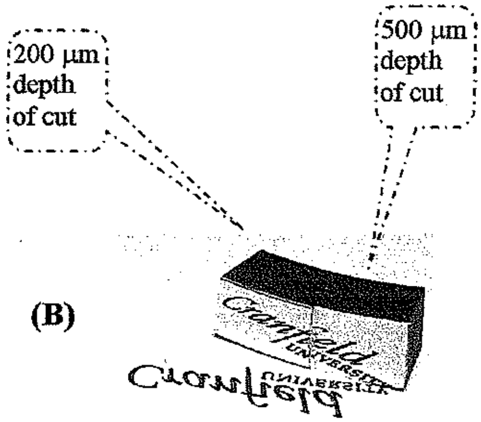


FIGURE 2: **(a)** *Tetraform 'C', a Novel Design of Machine Tool* **(b)** *Mirror-finish Surface produced using the Tetraform Machine at Different Depth of Cut.* *(Photo courtesy: Cranfield University)*

1) Identification and manipulation of atoms and molecules (nano-fabrication)

2) Formation and control of nano-structures on the surface and at the interface of materials

3) Spin electronics (micro-actuators) and

4) Theoretical analysis on atoms and molecules bonding, mechano-chemistry.

Some of the significant milestones achieved in Japan are:

- Discovery of carbon nano-tube, an ultra-fine carbon material measuring several thousandths of a human hair in diameter which can be used to regulate electric currents [35]. (See **Figure 3b.**)
- Introduction of a personal computer that uses a battery containing a type ofnanotube (NEC, Japan).
- Nano-enhanced, energy-saving flat panel technology for computer displays and televisions. (Mitsubishi).
- The building of circuits using nano-tubes (Fujitsu).
- Development of magnetic force probe microscope with finest resolution.
- Ultra-high density, magnetic storage accelerated.
- Active targeting DDS nano-particles for missile drugs.
- Thin films of highly-oriented, single-wall, carbon nano-tubes.
- Development ofultra-fine, ink-jet technology [36].
- Material design of half-metallic ferro-magnet and the synthesis.
- Carbon nano-tube for optical communications.
- A scientific understanding on photo-induced, phase transitions in nano-structures.
- Metal/semiconductor hybrid nano-material.
- Ink-jet technology for the formation of ultra-fine dots less than 1/1000 the size of currently achieved [36].

TABLE 2: *Major Nano-Developments across Europe*

Major Nano-Tech Labs in Europe	Technology	Application
• Cranfield University, UK	- Laser Etching	□ Advanced Optics
• Katholiekw Universiteit, Belgium	- Energy Beams	□ Computer Discs
• Physikalisch - Technische Bundesanstalt (Germany)	- Quantum Theory	□ Advanced Turbines
	- Metrology	□ Aerospace Materials
• Institute of Micro-technology Mainz (Germany)	- Precision Engineering	□ Microwave Devices
	- Control Theory	□ Semiconductor Devices
• Forschungszentrum Karlsruhe (Germany)	- Actuators	□ Advanced Packaging
	- Materials Growth	□ Microsystems
• Neuschaefer_Rube PTB, Braunschweig, Germany	- Semiconductors	□ Thermal Imaging
	- Electrochemistry	□ Medicine
• Laser Zentrum, Germany	- Nano-phase powders	□ Environmental Protection
• Delft, Netherlands	- Microbiology	□ Water Monitoring
• TNO, Netherlands	- DNA	□ Smart Pills
• Fraunhoffer Institute, Germany	- Antobodies	□ Gas Sensors
• Eindhovan University of Tech, Netherlands	- Genetheraphy	□ Medicine
	- LIGA	□ Polymer (Paints)
• NPL, UK	- Micro-forming	□ Skin Cream Products
	- Advanced Materials	□ Tooling
	- Genetics	□ Automobile Components
	- Sol-Gel	and many more . . .
	- Nano-composites	
	- Ceramics Fabrication	

- Ultra-fine wiring of a few microns in width. (See **Figure 3(b)**.

2.3 Nano-technology Advances in the United States

In the United States, a "Nano-technology Infrastructure Network" was formulated to synthesise partnership between university/research labs/industries in order to share the resources and focused on fabrication, synthesis, characterisation, design, simulation, integration, education, training and outreach activities. A wide range of materials including silicon, compound semiconductors (III-V in particular) and novel and unusual materials (including polymers and ceramics) are processed to produce nano-structures. Extensive research was done on lithographic process and tooling to create most substrate shapes, including small and irregular shapes and sizes as small as 30 nm. These innovations are the foundations for nm-scale, scientific exploration and technology development. Dry etch technology was developed for etching many types of semiconductors, metals and dielectrics. Also, thin films of metals and dielectrics were successfully deposited onto a variety of host substrate materials by an extensive tool set including sputtering, reactive sputtering, electron-beam and thermal evaporation and plasma-based CVD systems.

The "Nano-technology Network" comprises over 60 labs spread across the region and trained nearly 200,000 practicing engineers with a total capital outlay of around US$2 billion since 2000 [37]. **Figure 4** illustrates the various developments of nano-technology, products and services at USA [1, 2, 5, 38-41].

2.4 Nano-technology Advance in Asia

In Asia, emphasis was laid on nano-manufacturing, particularly nano-metric surface generation through employing process like ultra precision cutting, ultra precision grinding, chemical mechanical polishing, ion beam machining, ultra-fast laser machining,

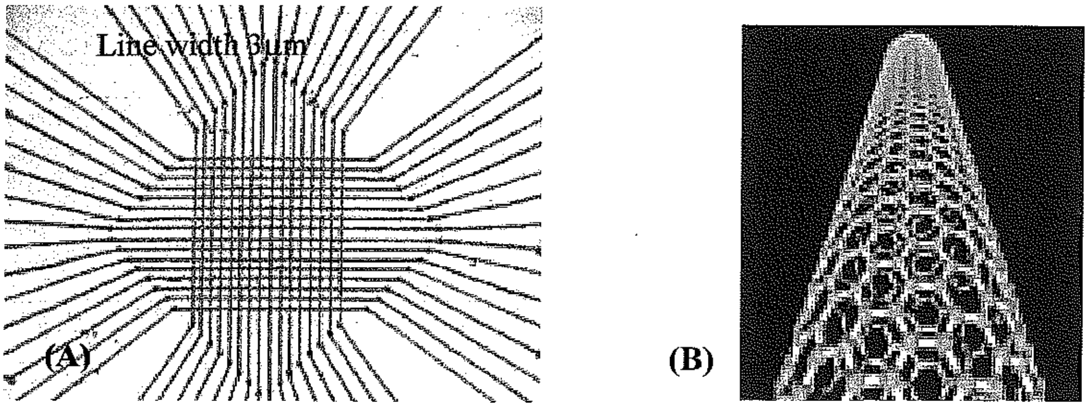


FIGURE 3: *Examples of Nano-technology Results at Japan*
(a) Ultra-fine Wiring of Line Width 3µm and
(b) Carbon Nano-Tube

elastic emission machining and other micro-machining methods [42-56]. The challenge vested with critical depth of cut (1~2μm) for achieving mirror-finish, nano-metric surface was resolved using micro-indentation and material properties analysis. This method has enabled to achieve ductile regime machining, even for brittle materials. The machine designed for this process has an extremely low resolution of magnitude 2.5nm. Dataturn software extensively applied to create aspheric profiles in order to overcome astigmatism in the lenses [43]. In grinding, a new technique "parallel grinding" was established where the cutting edge is continuously renewed so that the work-piece profile error due to wheel-wear-related issues was controlled. Scientific techniques that use acoustics emission signals for understanding; tool-work contact behaviour, transition of ductile to brittle was developed to deploy in the commercial/industrial applications. Nano-amorphous, coating methods were devised for the tooling which achieves higher wear resistance. Prior to this coating, the tool surfaces were ground using ELID method at null, residual stress so as to achieve high bonding strength.

In semi-conductor manufacturing, nano-technology was applied in chemical, mechanical polishing, wire bonding, flip chip technology and BGA mounting. As a result, migration from small-scale integration (SSI) to ultra, large-scale integration

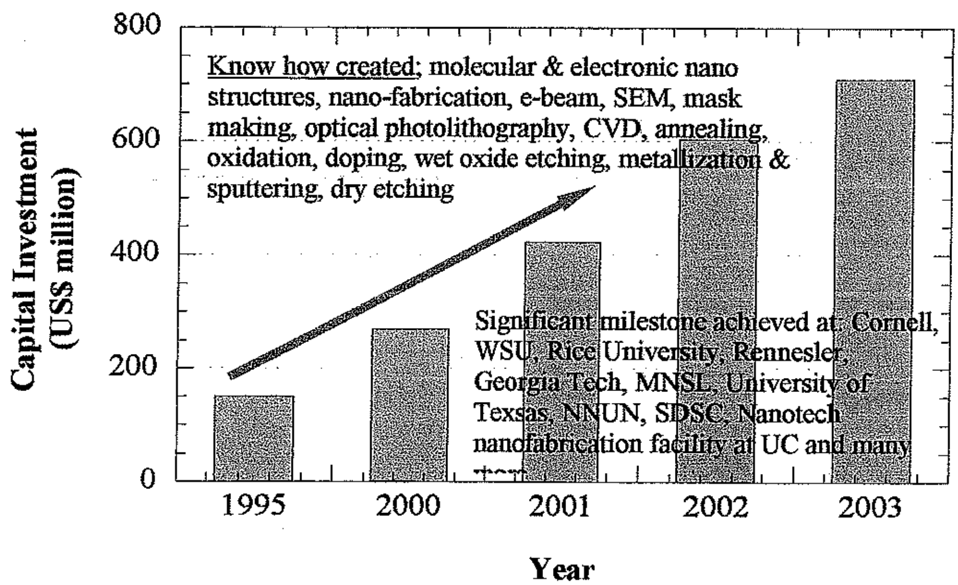


FIGURE 4: *Nano-technology Developments in USA and the Investment Scenario*

(ULSI) was achieved that ensures increased number of electronic devices on a chip of around 1 billion. However, such huge, volume integration of devices dissipates more power and therefore new chip design innovations viz. Pentium 4 with micro-engineering features, are on the rise. Also, bulk micro-machining methods were developed to produce 1.5μm wall-thickness of aspect ratio = 20 on silicon-based material. Furthermore, using the nano-technology, biochips were produced to facilitate fine, drug delivery contact less needle and micro-fluidics gadgets.

Research labs in Asia like A*STAR-Singapore, PEN center-NTU-Singapore, ITRI - Taiwan, KAIST-Korea, AIT-Thailand, Tsingua -China, CMTI-India and other institutions have invested around US$2 billion with main emphasis on nano-manufacturing and trained nearly 30,000 workers.

3. Nano-technology Relevance to the CARICOM Region

The CARICOM region established since 1973 comprises of 15 member states, namely Antigua, Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, St. Kitts, Saint Lucia, St. Vincent, Suriname and Trinidad and Tobago. The member states share common objectives on trade-strengthening, sustained growth and economic independence.

The CARICOM region on the whole focuses on agriculture, light-manufacturing, food industries, garments, assembly-type industries, packaging, tourism, aluminum-processing and oil/gas-processing. Such diversified activities, except minerals and natural resources extraction are clustered in every member state. In context with manufacturing support services like tools-manufacturing for the oil-gas sector, aluminum-processing, packaging of food stuffs - agriculture items, assembly of electronic items and light-manufacturing are widely grown.

Numerous nano-technology products /services that are suitable to the CARICOM region were identified within the current scope of activities and innovations. Some of the potential applications and niche areas are given below:

- Oil and gas sectors use the earth impact drill that house nearly 20 to 50 nos of carbide button bits. These button bits interact directly with the hard-earth materials like cement, rock, scale and resin sand. As a result, wear and chipping of the button bits are widely seen and result in poor tool-life. Carbide tools with nano-film coating have already demonstrated improved performance and hence there exists a potential for nano-film technologies to a number of engineering components particularly on oil-gas sector.

- New ways of packaging that enhance the food-stuff freshness and durability has commenced and these packaging are configured using nano-materials. As packaging industries are widely seen in the CARICOM region, absorption of nano-technology-related, packaging methods would further improve the exports and set to improve the economy.

- Growing numbers of nano-technology-related applications in the manufacturing sectors such as steel-structural materials, water filtration to nano-level, automobile nano-paintings and many more can be evolved that is suitable for the CARICOM region.

4. A New Interdependent Approach to introduce Nano-technology into the CARICOM Region

Unlike the IT revolution, nano-technology cannot be realised without heavy capital investment, intensive R&D and support between industrialists, researchers and academicians. In the CARICOM region, there exists peaks of excellence at fundamental sciences and a protocol is needed through which this paper's theme can be used for establishing a mutually, beneficial nano-corridor. A new interdependent approach is proposed to work hand-in-hand with both national, regional and international partners to transform the scientific interest in nano-science and nano-technology into viable products and ultimately mass manufacture. This corridor is expected to realise nano-technology, hence to position the CARICOM as a whole for a competitive advantage in the nano-manufacturing services environment. This initiative lays down the underlying scientific and technological frameworks for nano-science and nano-technology that are relevant to the CARICOM

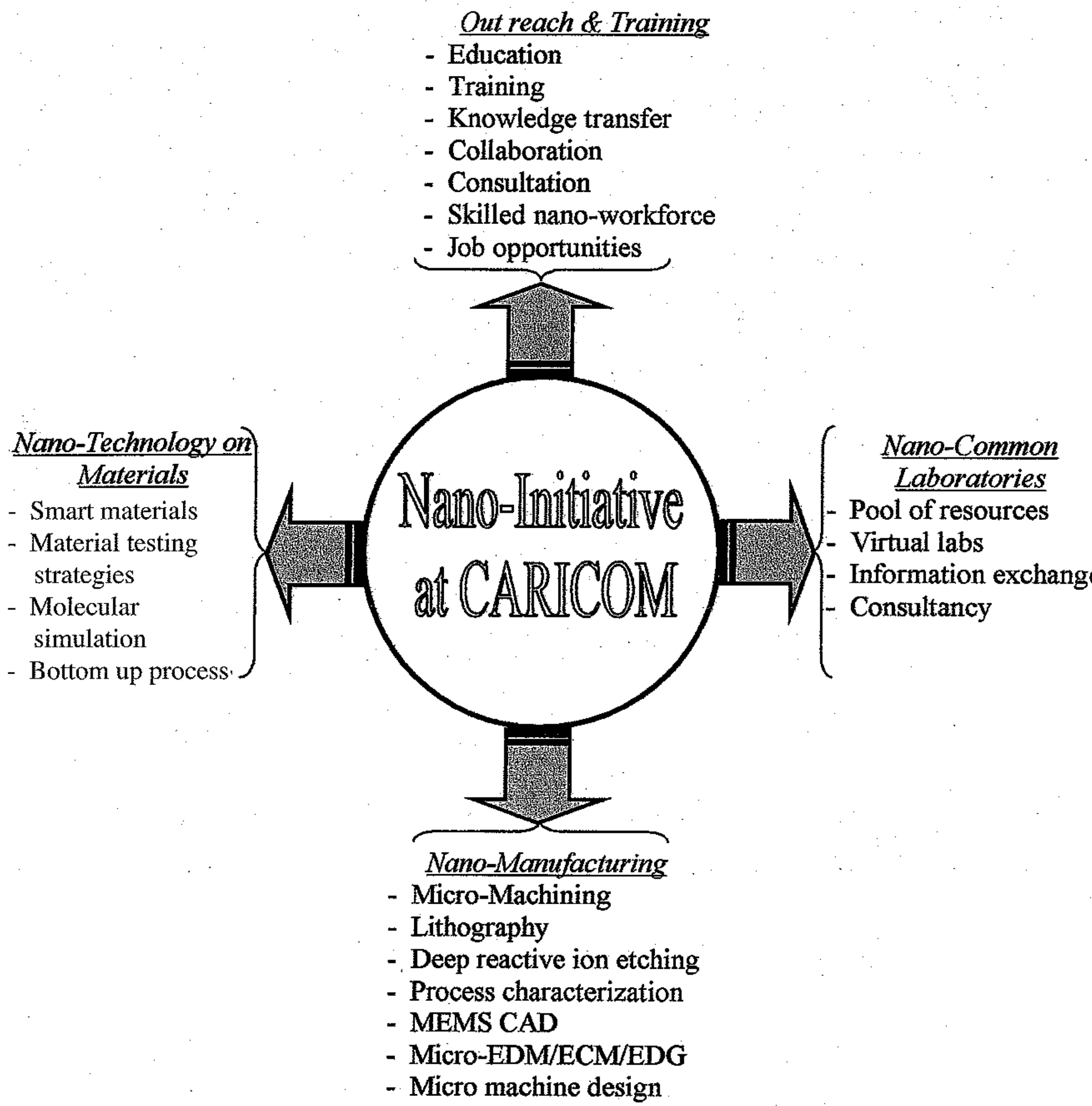


FIGURE 5: *Proposed Key Activities to Establish the Nano-Initiative at Caricom*

region. In order to establish the same, four key activities are proposed and shown in **Figure 5**.

4.1 Nano-common Laboratories

The nano-common laboratories would establish a pool of resources in the region and bring them under a single umbrella so as to work towards the common goal. In this way, all resources and innovative ideas would be effectively used. To further enhance the accessibility of resources, the formation of satellite labs is a pre-requisite. With this network of "virtual labs" that link various, regionwide facilities could promote easier access to information, expert advice and resources.

4.2 Nano-technology on Materials

Smart materials for delivering the nano-technology solutions would be formulated using the bottoms-up approach as the materials in nano-form are expected to behave entirely different with enhanced properties. A wide range of materials from polymers to abrasive powder is needed to harness the novel properties of the material especially when downsized to the nano-level. As the top-down approach of reducing the size does not hold good when the size becomes less than 100 mn and therefore as much as possible, a bottom-up approach method which focuses on material growth is emphasised.

4.3 Nano-manufacturing

Nano-manufacturing is about new ways of making things or devices at nano-scale. Methods developed for nano-fabrication in the >100nm size range will not work in the 20 nm range. Thus, it is necessary to develop an entirely new set of manufacturing methods for nano-structures. Micro/nano-manufacturing is set to play an important part, either directly for the product fabrication or for the manufacture of associated components like tooling, mold inserts, measuring devices and sensor elements. The following processes need to be considered:

- Measurement in micro-machining
- Deep reactive ion etching
- Molecular dynamic simulations
- Excimer LASER machining
- Micro-grinding
- Femtosecond LASER machining
- Diamond micro-machining
- Dry/wet etching
- Micro EDM/ECM/EDG
- Micro fluidics

4.4 Outreach and Training

Apart from the nano-manufacturing, every effort should be made to establish an infrastructure for education and training to cater for all levels starting from undergraduates to postgraduates, practicing engineers, executives, managers and even professionals. It will also ensure a smooth transfer of knowledge/technology generated in the labs to the industry through collaborations or consultations. This approach would also nurture talent in nano-science and nano-technology research and create a pool of highly-skilled workforce for the industry. A nano- training lab is necessary to be set up to provide training and lifelong learning opportunities for all research scholars, scientists, managers and executives. Furthermore, the knowledge generated at various satellite labs needs to be disseminated through conferences and seminars.

5. Conclusions

This paper has discussed the nano-science and nano-technology indicators around the world in terms of process, investment, application and its relevance to the CARICOM region. Although nano-technology is still an emerging area, massive commercialisation of products have already commenced particularly in optics, communications, semiconductor, display devices, bio-related products and even consumer products. The global study has revealed the technological development on nano-materials, nano-fabrication and thin films and its impact as a whole. Top-down or bottoms-up is proposed for nano-materials formations depending upon the nano- structural dimensions. The breakthrough on carbon, nano-tubes innovation has triggered serious nano-developments around the world especially in Japan, Europe and USA. The CARICOM region is set to improve its economy on energy, agriculture, manufacturing (light industries and services), small business, information and communication, infrastructure, transportation and culture. Adaptation and innovation of nano-technology on these areas would give more leverage to this region through market acquisition and hence position itself better.

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