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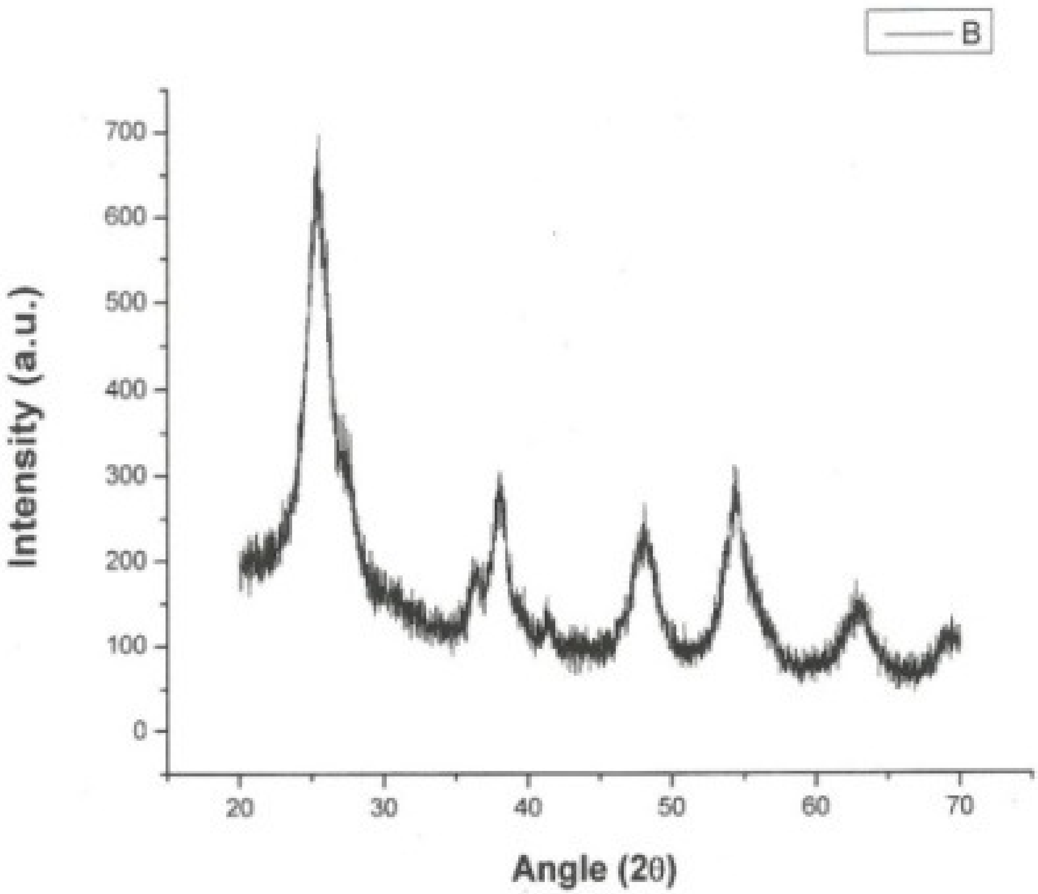

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Content

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Editorial

Nanomedicine is the application of nanosciences and nanotechnology to medicine: Nanomedicine includes monitoring, control, construction, repair, etc of the human biochemistry using nanochemicals and nanodivices.

The global market for nanomedicine in 2010 and 2011 were $63.8 billion and $72.8 billion respectively, according to report published by BCC Research. The market is expected to reach between $140-160 billion in 2016 according to some reports.

Nanotechnology will revolutionize the health system. More efficient tablets will be produced that will have little or no side effect. Drug delivery system will target exactly areas of need in the body. Drugs will become more efficient and cheaper. Nanosensors will be capable of dictating diseased cell at early stage leading to prevention medicine. Wireless nanodevices will lead to continuous contact between patients and medical professionals and institutions; leading to proactive diagnosis and prevention. Devices like nanoboat will be able to repair damage cell (efficient) without any operation or radiotherapy, which damage healthy cells. Nanomaster will be able to identify diseases cell, kill them systematically and remove them. Such multifunctional drug delivery systems can be used as cures for elusive sicknesses and diseases like cancer, tumor, HIV/AIDS, Alzheimer, etc. Nanovaccines because they are produced at molecular scale at the same level of the body chemistry will be more and more effective that vaccines as available now. Advances in sensors will lead to self-diagnosis. More efficient filters will be built by the use of nanoparticles. These filters will be cheaper and more durable. It will be able to filter the smallest contaminants (bacteria, dusts, etc). Diapers and other sanitary wears will be made such that there will be sensors to tell parents when the children need to be changed. Clothes and others wears will notify the owner when they need change. Clothes will be self-cleaning (ability to remove stains). This current issue will explore nanomedicine.

Further this issue will report on nanotechnology and nanosciences development in Costa Rica and a comment on nanofiltration. The journal continues its tradition of being in the frontline of the emerging field of nanosciences and nanotechnology. My appreciation goes to those editors and authors who made this issue possible.

Editor-In-Chief

Dr. Ejembi John Onah

Professor of Chemistry, Nanoscience and Nanotechnology

President/CEO, Focus Nanotechnology Africa Inc. (FONAI)

Article

TiO_2 nanoparticles; it's antibacterial, anticancer and nanotoxicological impacts

* Yadav R.,[1] Saurabh Y.,[3] Saran D.,[4] Padam A.,[2] Sudhir S.,[2] Agarwal S.C.,[3] Angarwal A.[5]

[1]Department of Biotechnology, R.B.S. College, Agra, India.

[2]Central Drug Research Institute (CDRI), Lucknow, India

[3]Department of Chemistry, Agra College, Agra, India,

[4]Department of Physics, Institute of Basic Science, Dr. B.R.A. University, Agra, India

[5]Faculty of Engineering and Technology, Department of Chemistry, Agra

College, Agra, India

Abstract

We present the fabrication of water-soluble and biocompatible TiO_2 nanoparticles, its characterization and the photocatalytic capability towards antibactericidal, anticancer and toxicological action. The titanium dioxide nanoparticles at low pH have been synthesized by using sol-gel method. Normally they are typically insoluble in water. These are made water soluble by surface modification and characterized by XRD and TEM techniques. The XRD patterns revealed exclusive formation of anatase phase. XRD calculation (Scherrer's formula) and Transmission Electron Microscopic measurement are in good agreement. The particle size 20-30 nm shows better antibacterial, anticancer (Cervical cancer, Lung cancer, Breast cancer) and nanotoxicology effects.

Key Words: Surface modification, XRD technique, TEM, Reactive Oxygen species (ROS), Nanoparticles (nps)

Introduction

Cancer is recognized as a deadly disease, and approximately 10.9 million people worldwide are diagnosed with cancer. Approximately 45% of these cases have been identified in Asia, because of the high density of population[1]. Here each year 6.7 million people die from this disease that is around 12% of deaths worldwide[1, 2]. Sixteen million new cases are estimated every year by 2020. Mortality rate of cancer in the world is predicted to accelerate with an estimated 9.0 million death from cancer in 2015 and 11.4 million deaths in 2030.[3]

Traditionally, the most common cancer treatments were limited to chemotherapy, radiation, and surgery [4] but these anticancer treatments are nonspecific to target killing of tumor cell, may induce severe systemic toxicity, and produce drug resistant phenotypic growth. An exciting potential use of nanotechnology in cancer treatment is the exploration of tumor-specific thermal scalpels to heat and burn tumor[5]. Nanoparticle is being actively developed for tumor imaging in vivo, bio-molecular profiling of cancer biomarkers and targeted drug delivery[6]. Nanotechnology is the revolution of present century. Using nanotechnology we can design present drug into nano level which can enhance the activity of drug. Advances in nanotechnology proved that nanomaterials are highly potent soldiers in the war against cancer. It is speculated that nano-particles between 10 and 100 nm in diameter will be optimal for tumor penetration[7].

Nano-particles offer a new method tumor targeting, already available in clinical practice, which can improve the efficiency and decrease the toxicity of existing or novel anticancer agent[8]. In recent years titanium dioxide has been extensively used as an environmentally harmonious and clean photocatalyst, because of its various qualities, such as optical properties, low cost, high photocatalytic activity, chemical stability and non toxicity[9].TiO_2 is a semiconductor with a bulk band gap of 3.2 eV which can produce reactive oxygen species (ROS) such as hydroxy radical, super oxide anion and hydrogen peroxide in aqueous medium under UV light[10].These ROS can drive several chemical reactions due to their high redox activity and efficiency to inactivate micro-organisms. In recent years, experiments have been performed by using either commercially available Degussa P-25 or TiO_2 nanopartials can be applied towards cancer treatment also.[11] One of the major limitation of using TiO_2 as photocatalyst is their relatively low value of overall quantum efficiencies, combined with the necessity of using near ultraviolet radiation. Some success in enhancing the photocatalytic activities is obtained by the preparation of TiO_2 nano particles.[12] Several methods of TiO_2 preparation have been reported in literature based on the hydrolysis of acidic solution of Ti (IV) salts. Also, oxidations of $TiCl_4$ on gaseous phase[13,14] and hydrolysis of titanium alkoxides[15,16] have been used to generate finely divided with a high purity TiO_2 powders. Photodynamic therapy (PDT) is one of the emerging treatment modalities for cancer that takes advantage of the interaction between light and a photo sensitizing agent to initiate cell death[17].Photodynamic cancer therapy is based on the destruction of the cancer cell by U.V light generated atomic oxygen, which is cytotoxic[18].However the use of nanoparticles in nano PDT is still under primitive stage. Our study concentrates on the synthesis and characterization of TiO_2– nps and their biomedical applications.

Experimental

Materials and Equipment:

$TiCl_4$: LOBA Chem, Purity 99.9%, HCl : Fisher Scientific, Qualigens,assay (acidimetric) 35-37% , Purity 99.9%, Mac Conkey Agar Media : Sorbitol MacConkey II Agar with Cefixime and Tellurite, Himedia laboratories Pvt. Ltd., India,Centrifugation machine (Spinwin) XRD Philips X'pertpro Panalytical X-ray diffraction & Rigaku miniflex., TEM (MORGAGNI 268D,Fel,USA).

Method of Synthesis

Precursor $TiCl_4$ was added drop wise and under stirring to 100 ml of water at about 0^0C the TiO_2 solution was dialyzed at different pH (2, 3, and 5). The solvent was removed by slow evaporation under dry conditions[12].

Surface modification of TiO_2 nanoparticles

As synthesized nanoparticles of TiO_2 are water insoluble, in order to make them water soluble, surface modification is essential.

Method

1 gm of TiO_2 was mixed well in 20 ml of water in a round bottom flask the mixture heated to 70^0C with stirring at 1000 rpm for 1h. 5 gm of citric acid (dissolved in 1 mL of distilled water) then added to the above solution and centrifuged.

Materials Characterization

The TiO_2 nanoparticles powder was analyzed by x-ray diffraction (XRD) technique for phase identification and cross checking of our results. Transmission Electron Microscopy observations were used for exact particle size, shape, distribution and agglomerate observations.

Antibacterial activity of TiO_2 nps against E.coli (Spread plate colony counting method):

Preparation of TiO_2 different Suspension

Bacterial cultures of Escherichia coli were prepared on Mac Conkey's Agar different amount of TiO_2 were used in this study Nanomaterials were added to the bacteria cultures. Tab. 1 Volumetric contents of nanomaterials the antimicrobial activity against Escherichia coli was evaluated by counting the number of colonies. One of the goals of the research was to examine the antibacterial properties of TiO_2 materials.

Sample	Bacteria Suspension Volume [mL]	Volume of sediment materials (mg) in distilled Water [mL]
1.0: 25	1.0	25
1.0: 50	1.0	50
1.0: 100	1.0	100
1.0: 250	1.0	250

Table 1. Volumetric contents of TiO_2 nps

Result and Discussion

Sol-gel route is a very convenient method of preparation for nps. TiO_2 nanoparticles were successfully prepared (no agglomeration).TiO_2 nps prepared by hydrolysis of $TiCl_4$ in aqueous solution. The size and morphology of grain was found to depend on a few parameters such as pH, hydrolysis temperature, $[H_2O]/[Ti^{4+}]$ ratio and thermal treatment conditions. When $TiCl_4$ hydrolyses, TiO_2 particles as well as H^+ and Cl^- ions were generated. The process can be described by the following reaction:

$$TiCl_4 + 2H_2O \longrightarrow TiO_2 + 4H^+ + 4Cl^-$$

When $TiCl_4$ was added to aqueous solutions, the heat of exothermic reaction was observed. As synthesized, the nanoparticles were insoluble in water due to hydrophobic capping ligands. In order to make them water soluble, surface modification with citric acid of this nanoparticle was performed. After surface modification TiO_2 nanoparticle were 80 percent soluble in water and biocompatible.

Characterization of TiO_2 nanoparticles (XRD analysis of TiO_2-nps) the phase identification of samples were conducted with X-ray diffraction analysis. Powder X- ray diffraction was used (I.I.T., Mumbai) for crystal phase identification and estimation of the phase (anatase, rutile) and the crystallite size of each phase present. XRD intensities of anatase (101) peak and rutile (110) were analyzed. The crystallite size can be determined from the broadening of corresponding x-ray spectral peaks by Scherrer formula. The crystallite size was determined with XRD peaks using the Scherrer equation:

$D = 0.9\lambda / B \cos\theta_B$

Where,

D = crystallite size/nm

λ = the wavelength of the X-ray radiation (Cukα)

B = the angle width at half maximum height

θ_B = the half dif

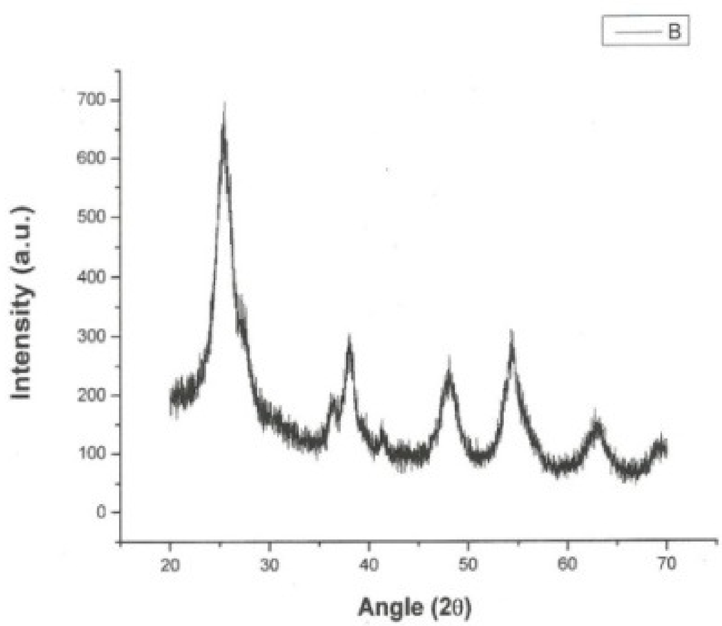


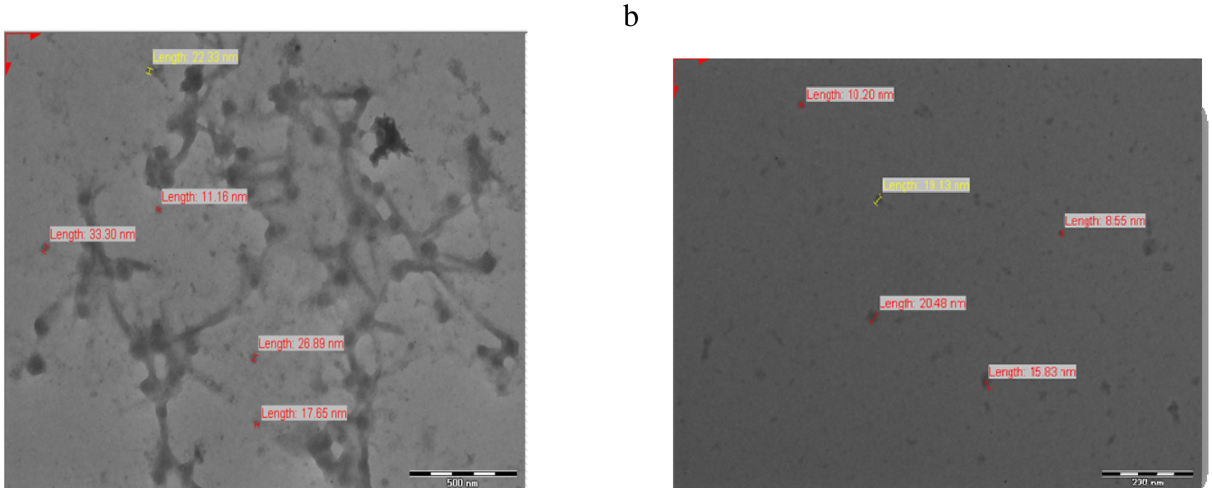
Figure 1. X-Ray diffraction pattern of TiO_2- nps dried at 120^0C

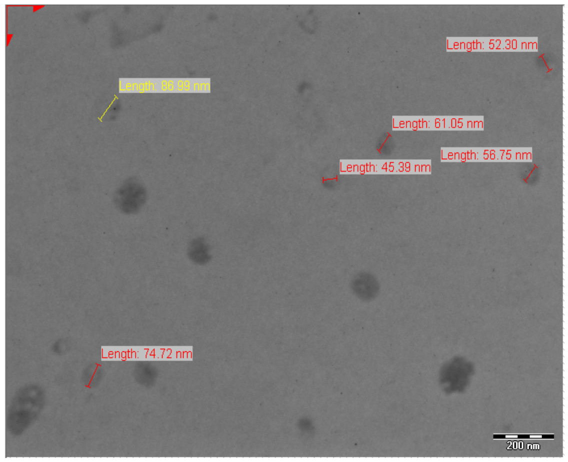
The XRD pattern of TiO_2–nps calcined 120^0C is shown in Figure 1. The result seems to that of anastase crystal formation. The signals appear to be rather broad due to the nano size. The three characteristic peaks about 111, 202 and 212 from TiO_2 nanoparticles. The average crystal grain size calculated using the Scherrer equation was found to be 12 nm. XRD analysis of this sample showed the presence of anatase and rutile phases close to that observed for TiO_2 (anatase). The crystallite size calculated from XRD peak broadening. The crystal size of TiO_2 was found between 10.16 nm and 12.37 nm.

Transmission Electron Microscope (TEM)

A modern transmission electron microscope (TEM) is sophisticated. Instrument for observing the internal structure of the material

a b





(c)

Figure 2. TEM image of Synthesized TiO_2 nps according to average particle size (a) 22 nm, (b) 15 nm, (c) 63 nm.

Transmission Electron Microscope (All Indian Institute of Medical Science) New Delhi was to determine the average particle size of TiO_2 nanoparticle. The result is shown in Fig.2. Particle size as measured from TEM and XRD both are in nearly good agreement with each other.

Screening of antibacterial activity

1mL of mixture suspension was sampled, added to the Nutrientagar (NA) plate and incubated at 37^0C for 24 h. After incubation, the number of viable colonies of E.coli on each NA plate was observed. The control experiment (E. coli + TiO_2 without light). Determination of antibacterial activity:

The antibacterial activity $I_{k\,\%}$ determined as $\boldsymbol{I_k \,\% = (I_k/C)^{*}}$ 100%

Where, I_k is an average number of bacterial colonies forming unit treated with nano-material, C is the average number of CFU in control group (without nanoparticles). The results shown in table 2

Sample symbol	UV irradiated samples I_k [%]
1.0: 25	34.39
1.0: 50	12.84
1.0: 100	0.17
1.0: 250	21.00

Table 2. The rate of bacterial survivability

CFU of bacterial cell is decreased with increasing concentration. While control environment (E. coli + TiO_2 without) have not changed. The UV rod irradiation on TiO_2 nps showed significant antibacterial activity. TiO_2 nanoparticle was easy to attach to the cellular membranes and accumulate. They were also easy to enter into the cytoplasm via phagocytosis.[13] It could lead to accumulation of (Reactive Oxygen species) ROS on the surface of cell membranes and in the cytoplasm. Hence under light irradiation, TiO_2 nanoparticle had more significant cell killing effect invitro.

E. coli is a simple Gram negative bacterium, non motile, non spore forming, non capsulated organism. The cell wall composition of E. coli consists of thin layer of peptidoglycon and a very thick layer of polyunsaturated phospholipids an integral component of the cell membrane. Hydroxyl radicals generated by TiO_2 to the oxidation of these membrane lipids which in turn lead to the creation of pores causing the destruction of cell wall followed by shrinkage of cell. Many functions such as semi permeability, respiration and oxidative phosphorylations by shrinkage of cell, are also affected as they are dependent on the intact membrane structure.

The initial oxidative damage took place on the cell membranes, where the TiO_2 photo catalytic surface had its first contact with intact cell. The membranes became somewhat permeable. At this stage the cell did not lose their viability. Photocatalytic action made the cell membranes permeable, intracellular components began to leak from the cell and free TiO_2 nanoparticles might also diffuse into the damage of cell and directly attack intracellular components.

Each type of nanoparticle will exhibit its own unique biological and ecological response that will also differ with shape and or size. It is important to realize that a wide range of nanoparticles have been shown to create reactive oxygen species in vitro and have the potential to induce cell damage.

Anti-cancer activity

PKA-1 and PKA-2 were tested at a concentration of 50 microgram / mL (the concentration used for in vitro testing of samples). The following cancer cell lines were used; KB (Oral cancer), C33A (Cervical cancer), MCF7 (Breast cancer) and A549 (Lung cancer). NIH/3T3 is a non-cancerous cell line (Fibroblast) Following Table shows % inhibition of growth of each of the cell lines used (e.g., 1.1 means 1.1% inhibition, 0 means no inhibition) Nocodzole was used as standard anticancer drug (positive control)

Cancer cell Lines	sample		Control
	PKA-1	PKA-2	Nocodazole
KB	0	0	98
C-33A	1.1	0	90
MCF-7	2.32	0	55
A549	2.71	3.23	98

NIH/ 3T3	28.13	0	40

Table 3. % inhibition of growth of each of the cell Lines used

* Above results are without UV, in presence of UV results may increase exponentially.

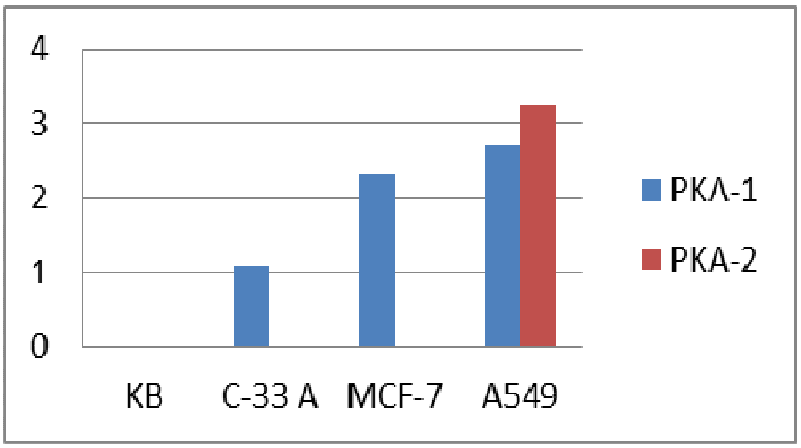


Figure 3. % of inhibition on different cell line, by PKA-1 and PKA-2

Sample PKA-1: is prepared at pH 3, at this pH prepared average particle size 15 nm.

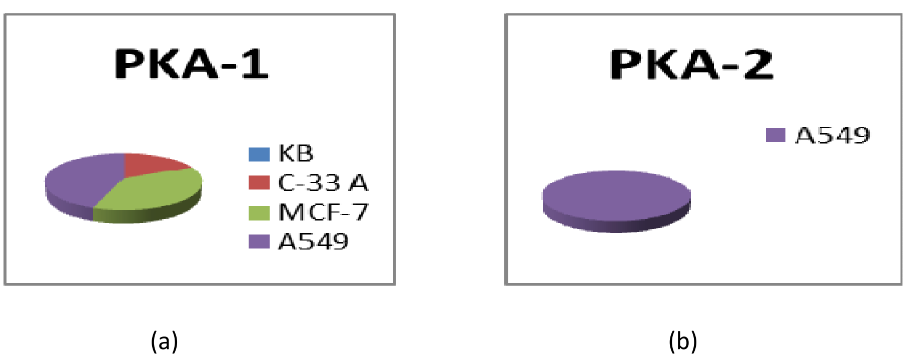


Figure 4. **(a)** % of inhibition by PKA-1 **(b)** % 0f inhibition by PKA-2

Studies on transmigration of (PKA -1) TiO_2 particles in various cancer cell line after vitro testing show that free TiO_2 nanoparticle about 22 nm. Sample PKA-2: was prepared at pH 2, at this pH prepared average particle size is 15 nm. Without UV and at low concentration (50 mg/1 anticancer pulmonary responses have been detected. Excellent result may be achieved in the system with UV irradiation.

In our experiment, the two types of TiO_2 nanoparticles used are PKA-1 and PKA-2, PKA-1 average particles size is 22 nm and PKA-2 particles size is 15 nm. Recent inhalation experiment with rats showed that nanoparticles (22 nm) had reached several organs after 24h of exposure and (amazingly) the central nervous system transportation via the nerves was at speed of 22 mm per hour.[14] So PKA -1 showed result most typical of cancer cell line C-33A, 1.1%, MCF-2.32%, AS49-2.71and they also show high toxicity (28.13%) on non cancer cell line (Fibroblast) and PKA-2 whose particle size is 15 nm. Showed activity against lung cancer only, because larger particles trans migrate from the alveolar regions to outside the lung more rapidly.

Toxicological Effects

Normally titanium dioxide (TiO_2) has been considered as non–toxic particle widely used in the fields of cosmetic, food and drugs when the scale comes to nanometer, TiO_2 nanoparticles exhibit specific characteristics coupled with unknown risk on health. Work of scientists suggested that TiO_2 is toxic to human and animals depending upon its route of administration, particle size, and dose. In our case PKA-1 average particles size is 22 nm and PKA-2 particles size is 15 nm. PKA-1 showed high toxicity (28.13%) on non-cancer cell line (Fibroblast) and in case of PKA-2 particles size is 15 nm. they showed only activity against lung cancer cell line and they do not show toxicological effects on non-cancer cell line. About the toxicity of TiO_2 nps Professor Susan Owens, of the University of Cambridge, said: "If we don't do anything and we leave it, then things manifest themselves in 10 to 15 years' time. By then the technology is so embedded in society it's very difficult to deal with it."

Conclusion

TiO_2 nanoparticles were synthesized successfully by facile Sol-gel method at low pH. Results of structural analysis show that TiO_2 nps average dimension about 15, 22, 63 nm (for different sample).Result obtain in the study of cytotoxic effects of TiO_2 nano particle strongly suggests that low pH TiO_2 essentially contributes to the killing of the cancer cells compared to higher pH. Thus our results represent a promising basis for the future developments in the field. Indeed the application of TiO_2 based nanomaterials for the photocatalytic properties of such materials can be used for photo sterilization processes and cancer treatment. However, there is great need to optimize the system to achieve the desired effect.

Acknowledgments

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Review

Sustainable Nanotechnology Policies for Innovation in Costa Rica

Vega-Baudrit J. [1,3], Núñez-Corrales S. [1,2], Porras-Gómez M. [1]

[1]Laboratorio Nacional de Nanotecnología (LANOTEC)
Centro Nacional de Alta Tecnología (CeNAT)

[2]Dirección de Tecnologías Digitales
Ministerio de Ciencia y Tecnología (MICIT)

[3]Laboratorio de Polímeros POLIUNA, Universidad Nacional

Heredia, Costa Rica

Abstract
The policies presented in this article address the creation of the National Plan for Sustainable Development of Nanotechnology in Costa Rica (*Plan* Nacional de Desarrollo Sostenible de la Nanotecnología PNDN en Costa Rica). This attempts to answer the social, economic and political challenges posed by the importance and pertinence of nanotechnology and nanoscience in modern society and, in particular for Costa Rica. Similar plans exist in Brazil, Colombia, Argentina, Venezuela and Mexico, which in turn exhibit higher indices in nanotechnology development than their regional counterparts. It is important to remark that the appropriate development of nanoscience and nanotechnology is significant not only at economic, social and environmental levels but at the scientific level also; generation of new knowledge- and education+innovation. The sustainable growth of a country must be tightly linked to the design and execution of plans that foster increments in science and technology production directed towards generating innovation. Therefore nanotechnology, as stated in the XXI Century Strategy for 2050, is considered one of the four fundamental pillars for the development of Costa Rica. Apart from the creation of the National Nanotechnology Laboratory (LANOTEC) at the National Center for Advanced Technology Studies (CeNAT) in 2004, the Ministry of Science and Technology promulgated a Public Declaration of Interest of the Research in Nanotechnology and its Applications on May 16th 2011. This declaration motivates public and private entities, in agreement with their material possibilities and formally stated legal and judicial normative, to contribute to scientific research efforts in nanotechnology and its applications by means of financial, logistic and technical contributions.

Background

Nanotechnology is a term employed to define science and technology applied at the nanoscale ($\sim 10^{-9}$ m) that allow direct manipulation of atomic and molecular structures, bringing the possibility of fabrication of new materials and machines based on the rearrangement of these atoms and molecules.[1] This discipline stated in 1959 from the lecture "There is enough room at the bottom" by the physicist and Nobel Prize Richard Feynman.[2] The proposal contained in his lecture was so significant that he is recognized as the father of nanoscience, providing intuitions that would later be proven as correct. In essence, nanotechnology is the study, design, creation, synthesis, manipulation and application of materials, devices and functional systems that exploit phenomena and properties at the nanoscale in order to have fine-grained control upon matter. [3]

From 1959 on, the amount of discoveries related to nanotechnology and its applications have increased exponentially. Carbon nanotubes (CNTs) have become one of the most important ones. Sumio Ijima in Japan discovered these in 1991[4] and they exhibit mechanical and electrical properties that make them an excellent material for diverse purposes. Some of their (current and future) applications include fabrication of nanotransistors and fuel cells, increasing the sensitivity of atomic force microscopy (AFM), detection of pollutants and the development of super-resistive and superconducting materials. [5-9] Hangjie Dai, physicist at Stanford University, has discovered that CNTs within a length of 2000nm can detect ammonia and nitrous oxide. [10-11]

From a social point of view, recent discussions have been conducted on nanotechnology, the progress of developing countries and their mutual relation. Some authors agree that nanotechnology and nanoscience could bring new and better development options to these nations.[12] Nonetheless, without adequate financial support and education programs targeted at specialized human capital, nanotechnology could as well lead to an increasing divide between poor and rich countries.[13] In the case of developing countries nanotechnology is a strong candidate for solving problems such as water purification, efficient agriculture, malnutrition, personal medicine, clean energy and environmental sustainability. [14]

As an attempt to bridge the knowledge gap in nanoscience and nanotechnology between rich and poor countries, the organization of multiple events related to scientific proposals has occurred in Latin America with sponsorship of companies such as the CYTED Network and Intel. Thus, in 2004 the First Central America and Caribbean Seminar on Materials Science and Technology[15] was organized in Costa Rica thanks to the Iberoamerican Program of Science and Technology for Development (CYTED). On that occasion, Dr. Osmara Ortíz, international coordinator of the VIII subprogram indicated in a recent interview titled *"The region must unite to be competitive"* that

> "Iberoamerica is a diverse territory, rich in raw materials. However, we have the conflict of importing most materials while we export products with scarce value added. It is urgent to revert this reality [...] and there are significant advances in the region that accelerate the creation of new products. Still the crude reality is that few have access to equipment required for proper testing and analysis. We must not therefore forget that international cooperation lowers the cost of innovation [...], it reveals thus the importance of iberoamerican countries to unite in order to form a chain, where every country provides its strongest link such as certification, laboratories, testing facilities or experienced professionals"[16]

Dr. Ortiz with support from CYTED and the Spanish Agency for International Cooperation (AECI) organized the "II Iberoamerican Days on Materials Technology" in November 2005, Santa Cruz, Bolivia.[17] During the event, nanoscience and nanotechnology were reviewed at a deeper level and included participation of experts from Argentina, Colombia, Venezuela, Costa Rica and Puerto Rico amongst others. The fundamental goal during these days was knowledge transfer not only from theory and actual experiences but also of information and documentation accumulated by the most advanced research groups in the Iberoamerican region in order to facilitate the interaction between the attendees and the professors.

More recently participants of around 10 countries during a meeting of Public Macrouniversities Network of Latin America and the Caribbean, [18] celebrated at La Habana Cuba in April 2006, decided that nanotechnology development should be oriented towards creation of nanomaterials with the potential of having local or regional application to high impact problems. The latter should happen by means of national and international cooperation in such a way that research capacities and human resources in nanoscience, nanotechnology and nanomaterials are strengthened.

Apart from the development of a proposal titled "Regional Cooperation for the Development of Novel Nanomaterials with Potential Applications of Technological Relevance", four sub-areas were established for nanotechnology and materials science and technology development in Latin America and the Caribbean: (1) nanotechnology and its applications to renewable energy and the environment, (2) nanotechnology applications to human health, (3) nanotechnology applications to Information and Communication Technologies and (4) hybrid nanomaterials development.

During 2010 three regional level events related to nanotechnology were organized. A South American congress on nanotechnology was organized in Ecuador in June. On that same month the NanoAndes 2010[19] workshop took place with participation of countries from the Andes region and where Costa Rica was invited in order to share its experience with LANOTEC. Finally, by July the SLAP 2010 conference[20] was organized; this Iberoamerican congress holds great regional prestige and included renowned world-class polymer and nanoscience experts. This event also included the Costa Rican Nanotechnology Conference, first in Central America where at least one participant is expected from each country and Panama in order to accomplish, amongst many objectives, a Central American nanotechnology cooperation network; additionally Guatemala is expected to host the second edition of the series in 2012. Guatemala's incursion in this converging technology has occurred through the implementation of a specialization degree in nanotechnology with the help of experts from Costa Rica, Puerto Rico and Colombia.[21]

The purpose behind this article -apart from being an overview of the process and pertinence of development of nanotechnology in Costa Rica by means of existing facilities and human capital- is to establish high-level policies and actions that allow Costa Rica to benefit from the momentum that has been achieved and lead to both international scientific recognition and local innovation in terms of novel products based on nanoscience and nanotechnology.

Costa Rica and Nanotechnology: current status

For the last 10 years Costa Rica has made efforts to converge to the world trend of integrating industry -from small and medium enterprises to multinational corporations-, academia and governments. Better and deeper collaboration amongst these sectors translates into greater and faster national development. In that sense, the role of each actor is well defined. Corporations and companies, large and small, generate value by producing and selling goods. Academia provides two types of resources: first, human capital able to generate scientific discoveries and technological innovation and second, specialized facilities that would not be profitable to maintain by any industry. The role of the government is thus to promote actively the conditions into which international high technology industries relocate to national premises and to support academia. The latter is, in the jargon of Economics, to effectively solve the market failure created by the need of expensive facilities and trained people in nanoscience and nanotechnology that cannot be financed by industry and that by the satisfaction of that need more net value is generated than the cost of the initial investment. [22]

Multinational companies such as Intel, Abbot, and Baxter have developed facilities in Costa Rica due to many factors such as qualified labor, high literacy rates, political stability, market incentives and significant financial expectations. These expectations are substantiated by the Potential Leaders index in the UN Human Development Report 2011[23] where the country is ranked with high human development, better located than its regional counterparts. The acknowledgement of the quality of her human capital and of the social, economic and political conditions has put Costa Rica in the map of international investors related to nanotechnology and nanoscience. These companies more and more direct their efforts towards research, development and innovation rather than pure manufacture with the goal of solving specific problems that improve their products and swiftly adapt to the changing market needs. In this sense, Costa Rica can profit from the market dynamics of innovation as long as coordinated actions from all three actors jointly target the creation of more technical and technology jobs, more entrepreneurial opportunities and more high technology productive linkages.

Within this context the National Center for Advanced Technology Studies (Spanish: Centro Nacional de Alta Tecnología, CENAT) was created as an inter-university organ that specializes in the development of advanced research and graduate degrees in technology areas as well as in linking government and industry by means of innovation projects. CeNAT was founded under the auspice of the Coordination Agreement for State Universities in Higher Education during the session no. 5-99 of March 2nd 1999 of the National Council of Rectors (Spanish: Consejo Nacional de Rectores, CONARE). [24] The rectors of the four state universities are the constituent members: the University of Costa Rica, the Costa Rica Institute of Technology, the National University and the Distance Learning State University.

The main objective at CeNAT is to provide Costa Rica of pertinent technology for ensuring international competitiveness in all sectors (social, economic, environmental) through planning and execution of training courses, research services, special science and technology services and strategic vision. One of the areas CeNAT addresses is Materials Science and Engineering and Microsensors. Within it and thanks to support from diverse in-country entities such as the Ministry of Science and Technology (MICIT), CONARE, CeNAT and international organizations such as NASA[i], LANOTEC was inaugurated on August 31st, 2004.[25-28] Research activities started on October 18th that same year.

LANOTEC has strengthened the country, allowing it to become a leader in nanoscience and nanotechnology via the application of top-level engineering solutions for studying advanced materials.[29] It includes design of and training in technologies associated to microtechnology, nanotechnology and materials science and engineering with particular purposes in mind. It also has allowed broadening of diverse areas of knowledge and contributes highly specialized human capital for scientific research in nanoscience and nanotechnology. Some of the development areas LANOTEC has impacted on are metallurgy, materials science, polymer manufacture, microbiology, medicine, geophysics and space exploration amongst others. Knowledge generation of the above sort has a strong potential of becoming a source of commercial innovation and overall economic development for the country and its collaborators.

Having in mind the latter discussion, LANOTEC has targeted its vision towards becoming a regional leader in nanoscience and nanotechnology. Four strategic research and development areas have been identified and established as key for the laboratory: (1) nanotechnology and renewable energy, (2) nanotechnology and human health, (3) nanotechnology and information and communication technologies and (4) hybrid nanomaterials. Along with the above-mentioned lines, it also fosters scientific cooperation with universities and other organizations -national and international- in such way that bilateral and multilateral agreements result in technology transfer, products and process improvements. In turn, high technology contributions from nanotechnology - according to international experience- are beginning to lower the gap between rich and poor countries.[30]

The document titled “XXI Century Strategy: Knowledge and Innovation towards 2050 in Costa Rica” which has become a science and technology roadmap for the nation emphasizes heavily that, apart from cognotechnology, infotechnology and biotechnology, nanotechnology belongs to the “converging technologies that will define science and technology in the following decades”.[31]

What is LANOTEC?

LANOTEC was founded with the goal of establishing multilateral cooperation in science and technology between national and international universities and organizations. In agreement with CeNAT's broader objectives, the laboratory seeks integration of academic, government and industrial sectors that contribute to environment-friendly products and processes, promotion of novel industries and general improvements in the quality of life of the citizens with a sustainable approach.

Objectives

The objectives set at LANOTEC strive to achieve scientific development and productive impact.

- To perform research in micro and nanotechnology focusing on nanostructures, micro and nanosensors and advanced materials with potential applications in energy, the environment, human health and information and communication technologies.
- To become training facility for nanoscience and nanotechnology in joint collaboration with government institutions, companies and academic programs at the state universities.
- To establish strategic partnerships with high technology industries (national and foreign) for the development of specialized services and products that generate added value and promote growth in the national productive sectors.

Mission

To perform scientific research, promote education and provide technology development services in nanoscience, nanotechnology and related disciplines that contribute to the advancement of Costa Rica by positively impacting the academic, government and industrial sectors through knowledge transfer in science and technology and specialized human capital.

Vision

LANOTEC is aligned with ethical values that transcend science and technology into social considerations, including a profound respect of human rights to life, liberty and security of all individuals. Additionally and in line with the national goal of a carbon-free economy, all products and services include analysis of their environmental impact in order to prevent generation of waste.

It is also expected for LANOTEC, with help of external collaborators, to become an innovation and business incubation center. The latter can include from development of scientific services and laboratory analysis to product design and testing. Nanotechnology has a definite advantage as a converging technology: its results are tangible and scalable. In order to ensure excellence and high quality results, every project is analyzed in order to maximize the efficiency of its solution.

Multidisciplinary collaboration is essential for success in this discipline, and team building is a central element that is fostered in the laboratory. Guiding values in the day-to-day laboratory activities are ethical behavior, scientific integrity, responsibility, proactiveness and recognition of individual and collective efforts.

With all the above, LANOTEC has the necessary elements for growing into a regional leader in a sustainable fashion. In a synthetic view, the vision at the laboratory is to become as a referent of professional performance in nanoscience, nanotechnology, micro-sensors and advanced materials at each of the activities it carries, from research and education to industrial applications in Costa Rica.

Facilities

The National Nanotechnology Laboratory was founded in August 2004 with seed funds from the Costa Rica-United States Foundation (CRUSA)[32] and the Incentives Fund at the Ministry of Science and Technology, starting operations in 2006. CeNAT contributed initially with 300m^2 of floor space dedicated to offices, lab rooms and a class-100 clean room. The latter contained equipment for CNT synthesis and an Assylum Research atomic force microscope (AFM).

LANOTEC currently has advanced technology equipment that amounts to over three million dollars.[33] These instruments are vital to fulfilling the mission of the lab in relation to nanotechnology in Costa Rica due to some significant reasons:

- High technology equipment is acquired and shared at a single location where clear policies facilitate usage of costly resources, enabling research and product development otherwise not affordable to individual organizations.
- LANOTEC, conceived as a point of collaboration, allows convergence of the private and public sectors by means of research and development for innovation in new products.
- In contrast to the mechanisms present at the state universities to establish public-private ventures and handle private funds, CeNAT has the advantage of a Foundation for Advanced Technology (Spanish: Fundación de Alta Tecnología, FunCeNAT[34]) that is not restricted by the traditional legal restrictions of public administration and whose legal figure has been established by law for such purpose. As a derived advantage, it has the lowest administrative overhead of all academic foundations, which makes it a preferential option for both government and industry.
- Being at the heart of CONARE, LANOTEC has the recognition of all four state universities and has a status that, in conjunction with other institutions such as the Ministry of Science and Technology, permits direct collaboration with leading scientists and technologists in the country for solving high priority needs.
- Advanced scientific instruments increasingly position Costa Rica as a regional leader in nanoscience and nanotechnology as well as a strong collaborator in research proposals.
- New research areas become possible such as bionanotechnology and others such as genetics, microbiology, polymer science, advanced manufacture, electronics, computing, pharmaceutics and biomedicine are strengthened.
- Novel techniques, available at LANOTEC, complement and enhance the possibilities brought by other existing characterization instruments and techniques such as transmission electron microscopy, scanning electron microscopy, X-ray diffraction and infrared microscopy.

As a component of the operations plan deployed in 2006, several training activities were performed in order to generate the capacities that would later transform in intensive usage of the laboratory equipment. In June 2006 a representative of Assylum Research Co gave the course “Operation of the MFP-3D Atomic Force Microscope” during the Pan-American Advanced Studies Institute. The course was a significant component of the process of acquisition of the AFM with participation of representatives of the four state universities. Another course at the same Institute titled “Tools and Techniques in Nanoscience” -funded by the National Science Foundation (NSF) and the Department of Energy (DoE) of the United States of America [35] had the participation of 40 research scientists and graduate students from Latin America and United States.

The full laboratory equipment at LANOTEC consists of:

- An atomic force microscope (AFM) with sub-nanometer resolution from Assylum Research
- An optical confocal microscope that provides the ability of performing birefrigerance analysis
- A goniometer for contact angle and surface tension analysis from Rame-Hart Instruments
- A differential scanning calorimeter (DSC) from TA Instruments
- A thermogravimetric analyzer (TGA) from TA Instruments
- A Fourier-transform infrared spectroscopy (FTIR) analyzer coupled to an attenuated total reflectance (ATR) analyzer from Thermo (Nicolet) with a range from 200 to 11000 cm^{-1}
- A coupling system between the TGA and the FTIR-ATR for the kinetic analysis of the degradation of materials
- Chromatography instruments: HPLC, GPC and GC from Thermo Scientific
- A tensiometer for solids and liquids
- A water-content analyzer (Karl-Fischer)
- A nanocalorimeter with isothermal titration from TA Instruments
- A laboratory for chemical analysis (e.g. glassware, sonicator, rotavapor, ultrasound, ultramix, pH-meters, conductimeters, electric welder, thermometers)

As part of the continuing improvement plan, the acquisition of new equipment is essential to maintain a leading position in the field. A Raman spectroscopy instrument and viscosimeters will be key for broadening the types and quality of the analysis services provided at LANOTEC.

Significance of LANOTEC for Costa Rica

Nanotechnology has the potential to increase efficiency in energy consumption, help clean the environment and solve major human health issues. It brings new possibilities for advanced manufacture in terms of quality assurance, scalability and cost reductions. The publication titled "Societal Implications of Nanoscience and Nanotechnology" by NSF in 2001[36] estimated that within 10 to 15 years the global market generated by products and services related to nanotechnology would be close to one trillion dollars annually. In advanced manufacture alone, nanostructured materials are expected to impact the market in the range of $340 billions, similar to electronics and the semiconductors industry with $300 billions.

Transportation will largely benefit from nanotechnology: nanomaterials and nanoelectronic devices allow fabrication of lighter, safer and faster vehicles at a lower cost. Infrastructure is a key target for improvements in terms of durability and reliability of roads, bridges, sewing systems, freeways and railroads; the projected market for the aerospace industry alone amounts to $70 billions. Nanostructured catalysts with applications to oil refining and subsequent chemical processing and derivation have an estimated impact of $100 billion. At least one half of the production in the pharmaceutical industry might depend on nanotechnology, a market that could easily exceed the $180 billion mark.

The OECD is in the process of developing more accurate statistics and indicators that improve the measurement of the impact of nanoscience and nanotechnology in the global economy.[37] Even when stats from 2011 or beyond are not yet available, it remains clear that investments in Latin America are still insufficient in nanoscience and nanotechnology. Even when this reveals a lag between developed and developing nations, it represents an opportunity to leapfrog for small economies and swiftly position themselves in high technology markets if the appropriate measures are taken timely.

Nanotechnology-based products are smaller, less expensive, lighter, with multiple functions and require less energy and atoms to manufacture them.[38] Apart from the clear relation to green chemistry and its attempt to reduce unwanted residues and chemical waste, nanotechnology is important for a developing nation such as Costa Rica due to its nature, requiring no extensive land usage, labor and maintenance. It rather depends on and generates highly qualified human resources, and is productive and inexpensive requiring modest amounts of energy and raw materials.[39]

As a consequence of the latter, CeNAT decided to support national development -and thus contributing to the status of living of Costa Ricans- by creating and supporting LANOTEC from its early beginnings. All areas of interest at CeNAT (Materials Science and Engineering, Biotechnology, Advanced Computing, Advanced Manufacturing, Environmental Management, and Science and Society) intersect nanotechnology in a natural way.

Many institutions benefit from the services provided by LANOTEC thanks to the organizational structure present at CeNAT. Current and potential collaborators and clients are.[40]

- The four state universities
- High technology industries (national or foreign) with intellectual property rights over knowledge required for industrial production
- Government entities whose interests include attraction of foreign investments in high technology and in the development of local industry in this area
- Recognized foreign research centers and universities with interest in joint research by means of collaborative research projects and doctoral theses that have impact on high technology industries
- Other nations with interest in promoting science and technology through research funding
- All other organizations focused on the development of science and technology worldwide

LANOTEC encompasses many activities and efforts. Some of them are:

- Fundamental and applied research projects
- Technology innovation initiatives and projects
- Technology transfer between academia and industry
- Nanoscience and nanotechnology consultant services
- Training courses and seminars
- Other activities of interest according to LANOTEC's mission, vision and window of opportunity

For research and development projects, three main categories apply: According to LANOTEC perspectives, vision and continuous upgrade needs, many of the projects are proposed by its research scientists in order to develop knowledge that can be later used for applied research or services; the latter includes upgrade of scientific instrumentation, fundamental research or applied research. Another mechanism that is utilized by organizations and companies requiring novel solutions is the usage of the facilities at LANOTEC, generating knowledge transfer both into the specifics of the problem and general nanotechnology applications. Finally, in order to fulfill the role of collaboration with the state universities, some of the projects are developed in conjunction with at least two other universities with the goal of providing solutions to significant national problems. These are funded through the Special State Fund for Higher Education at CONARE.

LANOTEC has since its inauguration provided scientific research and services to a wide range of institutions, allowing knowledge transfer to flow between all actors since 2006. The critical mass in nanoscience and nanotechnology has been achieved since 2011 thanks to such collaborations and projects. These cover public, private and NGOs with particular needs in nanoscience and nanotechnology. Some of the following organizations have benefited from the facilities and projects at the laboratory:

- **University of Costa Rica**
  - ***Departments:*** Chemistry, Physics, Mechanical Engineering, Geology, Biology.
  - **Laboratories*:*** Materials Sciences and Engineering Research Center (CICIMA: Centro de Investigaciones en Ciencia e Ingeniería de los Materiales); National Laboratory of Materials and Structural Models (LANAME: Laboratorio Nacional de Materiales y Modelos Estructurales); Costa Rican Metrology Laboratory (LACOMET: Laboratorio Costarricense de Metrología); Atomic, Nuclear and Molecular Sciences Research Center (CICANUM: Centro de Investigaciones en Ciencias Atómicas, Nucleares y Moleculares); Cell and Molecular Biology Research Center (CIBCM: Centro de Investigaciones en Biología Molecular y Celular); Electron Microscopy Research Center (CIEMIC: Centro de Investigación en Microscopía Electrónica); Pharmaceutical Research Institute (INIFAR: Instituto de Investigaciones Farmacéuticas); Photonics and Applied Laser Technology Laboratory (LAFTLA: Laboratorio de Fotónica y Tecnología Láser Aplicada); Engineering Research Institute (INII: Instituto de Investigaciones en Ingeniería).
- **Costa Rica Institute of Technology**
  - ***Departments:*** Chemistry, Materials Science and Engineering, Biotechnology.
  - **Laboratories:** X-ray diffraction and Spectrometry Laboratory; Non-Destructive Control Laboratory; Moulding and Casting Laboratory; Corrosion and Materials Protection Laboratory.
- **National University**
  - ***Departments:*** Chemistry, Physics, Biology. Recently the School of Computer Science and Informatics has developed a program in Engineering Mathematics targeted at modeling and simulation in which there is interest in interfacing with nanoscience and nanotechnology projects.
  - ***Laboratories:*** National Polymers Laboratory (POLIUNA: Laboratorio Nacional de Polímeros); Industrial Materials Laboratory (LAMI: Laboratorio de Materiales Industriales).

- **Government institutions**
  - ***National Emergency Commission:*** complementary failure analysis in construction materials.
  - ***Costa Rica Social Security Organization:*** quality control in medical materials.
  - ***Costa Rican Institute of Electricity:*** collaborations with the Corrosion Laboratory and analysis of structural materials for maintenance of hydroelectric plants.
  - ***National Technical Education Institute:*** technical education in laboratory techniques and specialized material analysis.
  - ***Ministry of Transportation:*** stress, strain and deformation analysis for road infrastructure and modification of asphalts with nanostructured materials.
- **Industry**
  - ***Intel:*** Failure analysis and quality control, use of laboratory equipments.
  - ***High technology companies:*** Baxter, Cibertec, Tecapro, Dedica, Xeltron, Trimpot, Alcatel, Hewlett Packard, Abbot; product quality control.
  - ***Polymers:*** members of ACIPLAST (Costa Rican Association of Plastics Manufacturers) including Polymer, Durman Esquivel, Arteplast, Plasbana.
  - ***Adhesives:*** Kativo, Sur, Henkel
  - ***Metallurgy:*** Alunasa, Industrias Bending
  - **Bioprospection:** National Biodiversity Institute (INBio: Instituto Nacional de Biodiversidad)

The above list shows that LANOTEC has great potential for impacting national development, allowing new spin-offs based on nanotechnology and its applications and a transformation of technical educations in order to attract high-profile companies whose business is based on knowledge. For the latter to occur, it is essential to go beyond the scope of LANOTEC and CeNAT and coordinate with industry and government a coherent strategy

National Sustainable Nanotechnology Development Plan

In Costa Rica, the Ministry of Science and Technology has by law the responsibility of directing the general development of STI and ensure their adequate utilization towards national development. The National Plan of Science, Technology and Innovation [4] (PNCTi: Plan Nacional de Ciencia, Tecnología e Innovación) defines seven key areas, where Nanotechnology and Advanced Materials has a prominent role. LANOTEC as the National Nanotechnology Laboratory has as one of its goals to complement the PNCTi with specific political actions and implementation points that ensure a countrywide sustained direction.

The actions proposed below integrate with the PNCTi and seek to provide an implementation that considers all current and future players. A significant part of an effort is focused in ensuring sustainability and converting the human capital from other areas to nanoscience and nanotechnology. It is important to remark however that the summary of actions presented here requires planning and development on their own, a process that is ongoing at the moment and involves the three aforementioned sectors. Table 1 summarizes the required political actions that support implementation of the plan.

Table 1. Political actions and implementation points in the National Sustainable Nanotechnology Development Plan.

Political action	**Implementation points**
Analysis of the required national capacities for sustainable nanoscience and nanotechnology development in Costa Rica	1. Declaration of the creation of LANOTEC as a laboratory of national interest in order to guarantee its continued existence 2. A comprehensive study of the current investment in nanotechnology in Costa Rica 3. Development of digital infrastructure that facilitates new services, innovations and projects that can be fully utilized by sectors that require it
Strengthening of the National Nanotechnology Network (RENAN: Red Nacional de Nanotecnología), established during SLAP 2010 and the	1. Creation of a Web portal for academic exchange in nanoscience and nanotechnology in the region supported by its members in order to ensure its sustainability 2. Identification of new members and collaboration opportunities based on scientific exchanges and resource sharing 3. Development of science and technology projects in a multistakeholder approach
Evaluation of risks and opportunities in nanoscience, nanotechnology and the converging technologies in general	1. Development of joint workshops between academia, industry and government that, departing from the assessment of the current status 2. Identification of weaknesses and proper mitigation strategies 3. Identification of opportunities and strategic allies in nanoscience and nanotechnology locally and regionally 4. Establishment of a roadmap with milestones that allow measurement of the status
Fund raising at national,	1. Identification of international funding opportunities

regional and international levels	focused on nanoscience and nanotechnology development 2. Increasing use of existing resources as matching funds on order to foster new synergies
Design and implementation of a National Plan for Sustainable Development of Nanoscience and Nanotechnology with a 25-year horizon directed towards innovation	1. Development of new university policy that facilitates and allows joint research with specialized centers such as LANOTEC-CeNAT 2. Fostering and support of curricula development towards in technical education and graduate studies in converging technologies 3. Creation of public policy that promotes a proper financial environment for the development of nanoscience and nanotechnology, including remission of taxes on scientific equipment 4. Reformulation of education plans in a cross-level effort in coordination with the Ministry of Public Education 5. Development of a plan that increases retention of young talents at all academic levels, focusing on primary education 6. Implementation of projects between academia, industry and government that raise the state of the art by means of national and international funding 7. Promotion of publications and patents in indexed, top-class journals and conferences 8. Creation of policies that guide intellectual property in nanoscience and nanotechnology 9. Implementation of actions and policies in ICT that have a positive effect in the development of nanoscience and nanotechnology 10. Strengthening of the installed infrastructure, including scientific instrumentation, intellectual capital and human

	resources 11. Development of cultural elements that allow the general population to apprehend the terms nanoscience and nanotechnology with better depth 12. Promotion at a national scale of converging technologies, including societal, ethical and environmental issues

The above-mentioned actions are organized into five phases, structured to maximize the relationship between effort and available resources:

- ***Linking phase***. Identification, unification and optimization of the national capacities in agreement with the political actions.
- ***Priority management and triaging phase***. Decision-making according to existing risks and opportunities, including resource allocation for each specific action. The first module of the National Program for Young Talents and Promotion of Science and Technology Vocations.
- ***Growth phase***. Provisioning of more specialized equipment for analysis and characterization of nanomaterials and consolidation of LANOTEC as the official national facility for nanoscience and nanotechnology.
- ***Consolidation phase***. Execution of the actions in the plan with measurement of indicators that assess the degree of accomplishment.
- ***Sustainability and industrialization phase***. Development of spin-offs, venture capital-funded companies and nano-enterprises.

Opportunity areas for Nanoscience and Nanotechnology in Costa Rica [41-42]

Given the overall view presented above and the plan drafted in these pages, sustainable development of nanoscience and nanotechnology should address areas that benefit from the natural and human resources already present in Costa Rica. These include:

- Nanomedicine and drug design
- Nanobiotechnology
- Nano and microelectronics
- Environmental nanotechnology
- Waste reconversion from agroindustrial activities into biocompatible materials
- Nano and Microsensors
- Nanocatalysis
- Renewable energy sources
- Nanoscience and education

- Social and ethical aspects of the development of nanoscience and nanotechnology in Costa Rica

In order to design the specific elements of each area, a national dialogue will be engaged with all involved actors. These meetings and work seminars have the potential of revealing strategic niches and markets where Costa Rica can have impact by selling nanotechnology-based products with high impact. These activities require participation not only of industry, government and academia, but also of experts in diverse areas ranging from intellectual property to environmental issues. At the end of the consultation process a document will describe the main challenges and opportunities for the implementation of the National Sustainable Nanotechnology Development Plan.

1. Conclusions

Despite the fact that nanoscience and nanotechnology are in a state of initial progress, there is significant evidence that it is becoming a national driver of research and innovation. It has produced spillovers to other institutions by means of the creation of academic research programs (e.g. the Nanotechnology Research Program at the Costa Rica Institute of Technology). It is the responsibility now of the involved institutions to ensure representation from relevant sectors as well as the establishment of metrics, checks and balances that allows a both focused and fair development across the country.

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Commentary

Advances in Nanofiltration

Ugbolue S. C.
Focus Nanotechnology Africa Inc. (FONAI)

P.O. Box 763 Ithaca, NY 14851

Nanofiltration remains a veritable platform to address the problem of developing functional membranes that can simultaneously remove various organic and metal pollutants from waste water. Nanofiltration (NF) is a cross-flow filtration technology which ranges somewhere between ultrafiltration (UF) and reverse osmosis (RO). Industrial applications of nanofiltration are quite common in the food and dairy sector, in chemical processing, in the pulp and paper industry, and in textiles, although the chief application continues to be in the treatment of fresh, process and waste waters. Indeed, advances in nanofiltration can accelerate the realization of the goal to provide affordable clean water for the developing countries. Increasingly, greater research efforts are being directed towards the production of nanofibers and nanocomposite fabrication. Tremendous research activities have continued to exploit electrospinnng [1, 2, 3, 4] as the most notable technology available today that has been conveniently deployed for nanofiber production, although there is need for the full commercialization of the process. It is recognized that when nanofibers with high surface areas are functionalized by incorporation of photocatalytic catalysts and/or surface modification, such nanofibers can be applied to membrane filters to capture various organic and metal pollutants in wastewater treatment.

The BCC Research LLC in their Market Research Report showed that the global market for nanofiltration membranes increased from $89.1 million in 2006 to an estimated $310.5 million by 2012, a compound annual growth rate (CAGR) of 26.1%. The water treatment sector projected to account for 72.7% of total revenues in 2007, worth an estimated $70.9 million in 2007 is expected to reach $238.2 million by 2012, a CAGR of 27.4%. However, Frost and Sullivan in their US Membrane Separation Systems Market (2006) forecast the market to grow at a compound annual growth rate (CAGR) of 34.3% through 2015, and at a 37.2% CAGR from 2015 through 2020, reaching nearly $2.2 billion in total revenues by 2020. Thus, this commentary highlights some of the developments and advances in nanofiltration and expanding areas of application.

The large diversity of membrane separation processes results in a different optimization of membrane materials and structures for each process. Van der Bruggen et al [5] have shown the extent to which a single membrane type can be used in gas separation, pervaporation, and nanofiltration. Interpretation of transport and separation properties has led to the conclusion that the membrane SolSep 3360 is a multifunctional membrane fulfilling all requirements for the three separation processes. This can be achieved by keeping a good balance between the thickness of the top layer, steric hindrance during transport, and the effect of hydrophobicity/hydrophilicity.

Colloidal fouling is still one of the major impediments for the implementation of membrane processes, e.g. in the purification of surface water. Effects of fouling for several representative nanofiltration membranes during filtration of several types of colloids in different circumstances (pH, ionic strength) have been studied by Boussu et al. [6] It was shown that not only the membrane, but also the colloid characteristics are crucial to control membrane fouling. Also, large colloids with a negative surface charge seem to be the most beneficial for a nanofiltration process at neutral pH. Changing the pH changes the interaction forces between membranes and colloids and also between the colloids themselves. Thus a higher ionic strength leads to more membrane fouling in case of membranes with small pore sizes.

In another study Lovell et al [7] reported that present technological composite polymer membranes for water purification are limited in application and practical life by their susceptibility to foul with concurrent reduction in membrane permeability. Recent developments in graft copolymers have produced fouling-resistant nanofiltration membranes. Specifically, polyacrylonitrile-graft-poly (ethylene glycol) (PAN-g-PEG) coated membranes with size selectivity have been reported. Also Lowell et al [7] reported on similar membranes with the addition of grafted, charged groups to impart charge selectivity to the filtration properties of the membrane and permit the exclusion of salts. A membrane coated with a negative-charged, sulfopropyl-modified variant of the copolymer retains much of the fouling resistance while retaining simple salts. The specificity of the coated membrane and the effect of environment on its properties were reported.

Pesticides and hardness can be removed in one step. [8] The experimental retentions indicate that NF-70 is a suitable membrane for removal of pesticides. The matrix of the ground waters caused an increase of the pesticide retention, together with a decrease of the water flux through the membrane. Nanofiltration membranes (NF) are used in pretreatment unit operations in both thermal and membrane seawater desalination processes and as partial demineralization to seawater. In order to predict NF membrane performance, a systematic study on the filtration performance of selected commercial NF membranes against seawater is presented. [9] The NF90 membrane was able to reject both monovalent and divalent of all studied mixtures and seawater with very reasonable values but at a relatively low flux. It reduced the salinity from 38 to 25.5 g/L using a single-stage NF membrane at 9 bars. This makes NF90 more suitable for the pretreatment in desalination processes. NF270 can reject monovalent ions at relatively low values and divalent ions at reasonable value.

French research [10] has led to development of a selective nanofiltration membrane, now being used to convert river water into potable water. The Filmtec NF200 nanofiltration membrane can remove harmful pollutants (herbicides and pesticides) from river water while leaving beneficial dissolved minerals such as Ca^{2+} and $Mg^{2+.}$ The Dow Filmtec membranes are based on proven, spiral-wound, thin-film composite polyamide membranes and consist of 3 layers, an ultra-thin polyamide barrier layer, a micro-porous polysulfone interlayer, and a high strength polyester support web. The polyamide barrier layer provides high water flux, superior salt and SiO_2 rejection, and excellent chemical resistance. The thick, microporous polysulfone support layer provides the necessary porosity and strength characteristics and restricts compaction under the pressure of reverse osmosis operation. Filmtec membrane performance in nanofiltration and reverse osmosis applications has been well documented; they have high dissolved solids and organic rejection, low pressure operation, high pH stability, and are structurally very strong.

In spite of the progress so far achieved, there is concerted effort to search for a standard method for the characterization of organic solvent nanofiltration. Toh et al [11] described a method for the determination of the relationship between solute molecular weight and rejection, often referred to as the molecular weight cut off (MWCO) of the organic solvent nanofiltration (OSN) membranes. This method utilizes a homologous series of styrene oligomers spanning the nanofiltration range (200-1000 g mol-1). Good separation of the individual oligomers was achieved using liquid chromatography with a reverse phase C18 column. The good solubility of the styrene oligomers in many organic solvents makes cross comparison of membrane performance across these solvents possible. This method also allows the determination of the molecular weight at which a rejection of >99.9% occurs in different solvents, making it a useful tool to test membrane and equipment integrity.

The work by Ksontini et al [12] dealt with the preparation and the characterization of cellulose acetate membranes for the textile water treatment by ultra (UF) and nanofiltration (NF). The evolution of flow was analyzed and treated by a comparative study of the pH and time effects on the performances regeneration of prepared membranes. Also, the hybrid technology of flocculant sedimentation-tubular UF-NF-NF was applied to treat city landfill leachate.[13] The influence of different operating conditions, such as pretreatment method, membrane modules and operating pressure, on landfill leachate treatment was investigated. Only around 10% - 15% of the permeate solution remained as the concentrated leachate, which may return to landfill pond or be incinerated after dehydration.

Lin et al [14] have proposed a continuous process for solvent exchange, a key unit operation for organic synthesis in pharmaceutical manufacturing. This process comprises a counter-current membrane cascade using organic solvent nanofiltration (OSN) membranes. The effect of process parameters, such as number of stages and flow rate ratio of replacing solvent to initial solvent, on solvent exchange performance are tested through simulations and experiments. Experimental results showed 47.8%, 59.2%, and 75.3% solvent exchange for single-stage, two-stage and three-stage cascades, values which are close to the 50.0%, 66.6%, and 75.0% respectively predicted by simulations. In general, the feasibility of OSN membrane cascades for continuous solvent exchange is demonstrated in this work.

Thus, it is evident that providing nanofiltration methods to developing countries, to increase their supply of clean water, have become a very inexpensive method compared to conventional treatment systems.

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