“A Voyage to Lilliput”
The Impacts of Nanotechnology on the Printing Industry

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Abstract: Nanotechnology promises to cause sweeping changes across every technology in our society in the next twenty years. These changes in computers, lighting, energy cells, batteries, bio-medicine and others hold the promise of a more efficient and more sustainable world in the future. But some of these changes are already starting to happen. The printing industry is one example where nanotechnology has already begun changing what we do now, and those changes will continue to impact us as time goes forward. A definition of “nanotechnology” is given, and a discussion of impacts on printing today and tomorrow are reviewed. The world of printing is changing rapidly and nanotechnology will increase that pace substantially.

Lilliput, the Land of Small

“Come with me on a voyage to Lilliput, the land of “small”, where wondrous things are being made.”

Lilliput is indeed an exciting land where nanotechnology is creating a technological tsunami that will affect the whole world in years to come. That wave of change has started to happen now, and so we will take a glimpse at “Nanotechnology” and see how it will impact the Printing Industry indirectly and directly for the benefit of all.

The language of Lilliput --- Nanotechnology

What is the definition of “Nanotechnology”? It has been defined in many ways, but one definition is as follows: NANOTECHNOLOGY is the technology dealing with matter and devices at extremely small dimensions, ranging from 1 to 100 nanometers, and fabricating those items by deliberately architecting those structures using atoms and molecules as building blocks.

These structures can be used as part of larger assemblies, and only one of three dimensions need to be in the described nanometer range. For example, a carbon nano-tube may have a diameter of 50 nm (nanometers) but be several micrometers long. A silver nano-flake may only be 40 nm thick but could be 500 nm wide and 800 nm long. In the purest form, a spherical nano-particle of aluminum oxide, or polystyrene could be 80 nm in diameter.

How these nano-structures are formed is also important. Theoretically, there are two directions that can be used to attain the size range indicated in the definition: “top-down” and “bottom-up”. In the top-down approach, for example, larger particles can be ground down to the nanometer range. .In the bottom-up approach, the nano-particle can be grown from smaller size items until the desired size is attained. This method more strictly meets the definition given above. This can be done by a variety of methods depending on whether the particle is inorganic (metal, ceramic, semi-conductor, etc.) or organic (polymer, dye, etc.) in nature. More complex structures could be a combination of inorganic and organic materials such as a core-shell particle having a polymer core and a silica shell. Examples of such processes are emulsion polymerization and sol-gel.

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Using the bottom-up process also allows the end material to be grown larger tan the 100 nm limit if needed, while still qualifying as nanotechnology. An example of this bottom-up approach used in the Graphic Arts is the "chemical toner". Dry toners were traditionally made and ground down and sifted to sizes ranging from 7 to 15 micrometers (microns). Today dry toners are chemically grown up to 5-7 microns that are responsible for the higher resolutions and better color rendition of modern digital printing devices. Newer developments are promising dry toners in the 3-5 micron size.

How small is a nanometer?

So far we have talked about nanotechnology without putting any perspective on the basic unit known as the nanometer. To appreciate just how small that is will take some definition and comparison. First, "nano" comes from the Greek for "dwarf" and is used as a prefix in the Metric system to denote 1 x 10^{-9} or 0.000000001. So, 1 nanometer is 10^{-9} meters or 1 billionth of a meter, or 1 millionth of a millimeter, or 1 thousandth of a micron. That is very small. [See Table 1]

That's also a lot of zeros to comprehend, so it might be easier to give some comparisons. A piece of writing paper is about 100,000 nm thick, the period at the end of this sentence is about 1 million nm in diameter, and an average strand of human hair is about 80,000 nm in diameter. A virus is approximately 100 nm in diameter. In fact, it would only take ten hydrogen atoms standing side by side to equal the width of one nanometer (assuming you could get them to stand still long enough)! That is very small indeed.

Relative Size in Nanometers	
Object	***Size Range***
person	**1,000,000,000 nm**
grain of sand	**1,000,000 nm**
human hair (thickness)	**100,000 nm**
red blood cell	**10,000 nm**
wavelength of light	**1,000 nm**
virus	**100 nm**
large molecule	**10 nm**
small molecule	**1.0 nm**
hydrogen atom	**0.1 nm**

Table 1: Relative sizes of common objects in nanometers as a reference

Why is Nanotechnology so important?

So we have established that Lilliput is the "land of small", and just how small that is; but why do we want things that small? How much different is it from microtechnology?

It turns out that when we reach the arena of nano-sized materials, we get results that are unexpected and not just extensions of the micro-sized arena. Material properties alter significantly, and sometimes behave in surprising ways. As a result we can do things not thought possible before.

One simple example of surprising behavior is that of gold nano-particles. The melting point of gold is an assigned value, which serves as a calibration point for the International Temperature Scale.

This is true at normal macro-size, and down to micro-size, and there gold melts at 1064.58°C. But when gold is reduce to the nano-size regime the melting point begins to change. In fact, when gold gets below 2 nm, it is reduced to <500°C.

For most of us this might be just an interesting bit of trivia, but if we are trying to print a flexible microcircuit on a plastic substrate with a conductive ink, and heat it to its melting point to get good conductivity without destroying the plastic, the gold nano-particles now make that feasible.

Another interesting behavior is that of the nano-crystals known as "quantum dots". These materials can emit various wavelengths of visible (even near Infrared) light when irradiated by Ultraviolet light. These extremely small crystals, some as small as 0.1 nm, all emit light with wavelengths many times larger than the diameter of the crystals themselves; namely wavelengths between 400-850 nm.

One pertinent application of these light emitting nano-materials would be their incorporation into an anti-counterfeiting ink for use in the security printing segments of the Graphic Arts.

Another important change in material properties occurs when the crystalline structure of metal is altered from a typical 20 micron size down to a 20 nm size. At this point, the strength, hardness, and flexibility can improve up to a factor of 10X. Just think what could be done with steel or aluminum that was ten times stronger! Lighter weight presses, gravure cylinders and all sorts of imaging and processing equipment come to mind.

By arranging carbon into precise nanometer-scale structures known as nanotubes, materials can be made that are up to thirty times stronger than steel, yet they are one sixth the weight. This technology is being studied today in the electronics and aerospace industries to reduce the size and weight of many items from cell phones to airplanes. How devices in the printing world might benefit from this?

Similarly, nano-composites have already begun changing many industries. By incorporating the appropriate nano-particles into a supporting matrix, the strength of the resulting nano-composite can be improved anywhere from two to twenty times. This also can be done in many cases while reducing the final weight of the device being made. A typical printing application would be a UV coating. Such a coating could be applied at half the typical coating thickness, be cured with less than half the energy, would be half of the added weight, and yet would be 5-10 times more abrasion and scratch resistant, without any loss in clarity or gloss. This would be of great utility for direct mail advertising and catalog printing applications.

Besides the changes mentioned in thermal, optical and mechanical properties, significant alterations in electrical, magnetic, chemical and biological properties have been, and are still being discovered. Many of these astounding changes will lead to improvements in data storage and transmission.

How are these changes possible?

These changes may sound like magic, maybe even too good to be true! However, there are sound scientific reasons behind them. As it turns out, size does matter!

As these particles reduce in size, the number of molecules contained in that particle diminishes, but the per cent of those molecules that are on the surface of the particle increases. A particle that is 5 nm in diameter has roughly 50% of it molecules at the surface of that particle. As a result, the behavior of nano-particle becomes dominated by the surface molecules not those in the bulk of the particle. This change can only begin in the nano-size region. [See Table 2]

Similarly, as the particle size diminishes, the ratio of surface area to particle volume increases; and in the nano-size regime, this enormous surface area can have a huge effect on the material properties. It also lends a greater efficiency to the use of the nano-materials in that a very small amount of additive can have a very large impact on performance.

Diameter in nm	Total number of atoms	Number of atoms at the surface	% at surface
0.7	10	8	80
1.6	100	60	60
3.4	1,000	400	40
7.3	10,000	3,000	30
15	100,000	10,000	10
34	1,000,000	50,000	5
73	10,000,000	100,000	1
156	100,000,000	200,000	0.2

Table 2: % of atoms at the surface of varying sizes of nanoparticles

It is these types of surface area impacts that are so vital to the improvements in nano-composites. Such enhancements in surface properties can also be important to the wetting or non-wetting behavior used in printing plates, and to reducing the wear in image and non-image areas as well.

These changes can also take place with little to no deterioration of the optical properties, such as clarity and gloss, since the nano-particles are so much smaller than the wavelengths of visible light.

[However, clever structures have been fabricated with asymmetrical nano-materials that drastically increased the reflectivity of lower layers within a solar cell and the transparency of upper layers in order to get much higher conversion efficiencies. Likewise, equally clever structures have been built to all but annihilate reflectivity in order to increase “invisibility” for military applications.]

What are some of the important applications of Nanotechnology?

The applications for Nanotechnology are far ranging. Since we are dealing with improvements in all material property areas, some of which are quite dramatic, the scope of this article can’t go into all of them in any great detail.

However, areas from biochemistry and medical applications have probably been the most publicized by the media. Although most people have heard little or nothing about nanotechnology, those that have heard about it probably equate it with Nanobots – such as independently mobile robots programmed to ride around the human body on blood cells doing a variety of medical repairs. Exciting, yes; scary, probably, but these are not the subject of this paper.
Neither are the various medical diagnostic tools or targeted drug delivery structures being considered, but I mention them because many of the dollars funding nanotechnology research is aimed at these applications, and because some of this fundamental learning will spill over into other areas, such as printing. Hydrophilicity and lipophilicity [we call it oleophilicity] are important in the medical world too.

Another huge area is electronics and computers. This can range from applications in flexible electronics on one end and hyper speed mini-computers and exabyte [10^{18} bytes] data storage on the other. Dramatic increases in computing speed, data storage, and display technology will obviously impact the printing world and everything else.

Energy is another overarching field that will impact us all. Improvements in battery efficiency, life time, weight to size ratio; efficiency of LED and OLED technology; efficiency in solar cells, hydrogen fuel cells; improvements in catalysts for fuel conversion or materials for hydrogen storage, will all be important.

Increasing the strength and decreasing the weight of materials will have huge impacts on transportation, shipping and mailing costs, energy usage and pollution.

Nanotechnology is the Road to Sustainability

In fact, the "green" aspects of nanotechnology may be some of the most important outcomes from all of these applications. By using smaller materials to get bigger changes, we can use less material at less total cost, and generate less waste and pollution while using less energy. This can all be done without sacrificing quality or performance or efficiency. In 2007 the existing nanotechnology application generated 8,000 tons less of carbon dioxide. By 2014 that is expected to grow to over one million tons less carbon dioxide! This is the real definition of sustainability.

When will these improvements be available?

That depends on the specific technology and the specific application, but some of these materials and methods are already beginning to be commercialized in areas like transportation, vehicles, paints and coatings, and electronics and computers.

Others are farther away, anywhere from 5-20 years in the future. But nanotechnology is not a passing fad, rather it is an enduring and fundamental change to our world, that some liken to the original invention of printing, or the industrial revolution, or the introduction of the automobile.

It is often compared to the advent of the computer and the electronics age, which was built upon microtechnology, the previous "size reduction" technology!

Nanotechnology will continue to mature and contribute improvements over the next 20-50 years.

The important thing for the printing industry is that materials built on nanotechnology are here now and will continue to improve in the near future.

Who is doing all this Research and Development?

It is being done all around the world. The governments of the existing industrial giants are pouring Billions of dollars into government supported research. So are the governments of the emerging nations, who see this as a way to "leap frog" into modern technology and growing markets. This work is being done in government run labs and universities worldwide. The US, as well as the EU, Japan and other nations, has initiated National Nanotechnology Initiatives. Similarly, individual States within the US have there own nanotechnology initiatives to stimulate employment opportunities. In 2007, the U.S government alone spent $1.4 billion in nanotechnology research. The rest of the world spent approximately an additional $3 billion.

Additionally the private sector is beginning to increase its participation and growth in funding now that the business opportunities are more obvious and trillions of dollars in future revenues are being projected. In 2008 alone, $150 billion worth of nano-enabled products are expected to be sold.

Why should the Printing Industry care about Nanotechnology?

The current business climate for the Graphic Arts is FLAT. Traditional printing methods are being besieged by alternative media choices. People are beginning to doubt [once again] the future of "hard copy" print. Government regulations and industry pressure are increasingly focused on the Graphic Arts world. Awareness over "green" issues like lowering VOC content, carbon footprint, solid wastes, recycling, etc. is growing and "sustainability has made it onto corporate radar screens across the world.

Growing industrial economies in emerging nations are using more raw materials thereby increasing the costs and decreasing the availability of crucial items such as steel, aluminum, petroleum and others.

The costs of shipping, mailing, waste disposal and energy continue to rise.

What's a printer going to do?

What are the primary impacts of Nanotechnology on the Printing Industry?

The biggest impacts and benefits to printers may well be the assistance in confronting these issues for printers just listed.

In order to improve the state of our industry we must become more efficient, more cost competitive, and more sustainable. To do this we must learn how to get more from less without losing quality or performance, and without losing competitiveness or profitability. Nanotechnology can help us do this. How? We can use less material: less metal, less ink, less paper, less over-coating, and by result less energy.

What are some of the specific opportunities and how do they relate to Nanotechnology?

What if, we were able to use aluminum plates for our litho presses that were 6 mil, instead of 12 mil, even for our largest presses? By using nano-crystalline metal structures that are up to ten times stronger, cutting the thickness in half should be no problem. Of course we would have to deal with packing in the transition; and we would want auto-loading of plates. But if we went in this direction, materials costs, shipping costs, and energy costs should all decrease.

What about lighter weight presses that would be just as strong and steady? By using nano-crystalline steel and nano-composites, this should be feasible. Again, shipping weight, materials use, and energy use [in making and running these presses] should decrease. This wouldn't happen overnight, but as new presses of all sorts [litho, flexo, gravure, digital, etc.] were added, the industry would benefit.

What if, we were able to use less ink? Using nano particles in inks that gave us better color and better rub resistance and adhesion to paper at half the thickness would certainly reduce costs. It may even reduce the need for UV inks or overcoats in some applications.

This type of nanotechnology improvement will be even more important in inkjet applications as nozzle sizes and drop volumes decrease in size to prevent clogging and improve drying. Drop sizes are coming down now close to one picoliter, but "femtoliter" drop sizes are being researched in labs now. A femtoliter is 1,000 times smaller than a picoliter!

Applications in security printing and electronics printing will also rely increasingly on nano-particle technology.

What if, we were to be able to reduce the thickness and weight of paper without losing strength or print performance? Nano-fiber technology could help reach this goal. Furthermore, nano-composite technology can now improve the coatings used on papers to use ink of all types more efficiently. Reductions of paper weight by half would have enormous impacts on shipping and mailing costs and fuel usage.
This would certainly help direct mail, catalog, magazine, newspapers, books, etc. The positive impact on land fills will be significant as well.

What if, we were able to reduce the thickness of aqueous or UV coatings on printed materials by half, and could use less energy to cure them, and have them withstand the rigors of automated mailing machines. All of this could be accomplished with no loss in gloss or transparency.

All of these changes have some impacts on energy uses, VOC emissions, carbon footprint, waste disposal and other “green”, sustainability issues as well.

Nanotechnology is not a panacea for all that ails the printing industry, but it can be an immense help in many areas. Even more importantly, some of this technology is available today.

Don’t delay – Time and competition are not standing still

Manufacturers that haven’t started investing in nanotechnology yet cannot afford to wait any longer. Other manufacturers around the world are already generating patents and products and profits.

Printers and print buyers who haven’t yet been asking their suppliers about nanotechnology application for printing should start now. And, they should be willing to aid suppliers in this transition for the benefit of the entire industry, and our world. Sustainability is s good thing. And the road to sustainability goes through Lilliput.

Changing ways of doing business

All of these potential benefits being discussed can only happen if we are willing to change.

We have to be willing to leave the past behind and give up our Brobdignabbian ways. Bigger is not always better. If a little bit is good, more is not always better. Using less does not always mean you will get less quality or performance. And you cannot get a different result by doing the same thing over and over again and expect a different result!

We must greet the future and adopt Lilliputian logic. Less can be more. Using less can mean getting more quality and performance along with less cost. If you want to get a different result, you have to do something different. Give nanotechnology a chance. Take the road to sustainability!

Welcome to Lilliput!

Where our favorite color is “green”,

Where beauty is skin deep,

And, where good things come in small packages!