On the Substance of Civilization in Human Society Entering into the Nanomaterials Age

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Accepted: March 8, 2011; Published: June 27, 2011

Abstract

To date, the developmental stages of substance civilization in human society have gone through the Stone Age, the Bronze Age, the Iron Age, the Steel/Cement Age, and the Silicon Age based in the dividing standard (typical materials) proposed by one of the authors. Further, we believe that human society has entered into the Nanomaterials Age. The developmental history of nanomaterial, the evolutionary process of nanomaterials during the Silicon material age, and the reasons that the world has entered the Nanomaterials Age are analyzed and discussed herein. In addition, we have identified the time when human society entered the Nanomaterials Age. Therefore, the theory of six eras of the development of human substance civilization has a complete exposition.

Keywords: Human society; substance civilization; Nanomaterials Age; theory of six eras.

1.0 Introduction

The development of substance civilization of human society has occurred over a very long period of time; typically, estimated more than 3 million years. What is an important and interesting subject is dividing this development into stages of human substance civilization. Therefore, we have proposed a standard for such division, which is based on typical materials. Specifically, for the division of human substance civilization, we have pointed out that, typically, it is rather disorderly and confusing, and there is no unified understanding or view for such a division. As such, we have proved that, only materials can, but others such as production relations and abstract names cannot act as the dividing standard. In our opinion, only the materials can satisfy several conditions for such division. The condition for typically materials include materials must be human made, materials must cause significant changes worldwide, and materials must withstand time.

Using this standard, we have written another paper [1] that discusses the division of the development stages of human substance civilization from ancient times to the present. In doing so, we have found that the development of human substance civilization has gone through five ages, the Stone Age, the Bronze Age, the Iron Age, The Steel/Cement Age, and the Silicon Materials Age. The content of each age, their evolution, and the translation of one age to the next are analyzed and discussed. Of importance to researchers is the categorization of our current era (e.g., Late-Silicon Age, Silicon Age, or some other currently unnamed era). According to the dividing standard, we are sure that the present substance civilization of human society entered the Nanomaterials Age at the beginning of the new century. In other words, to date the development stages of human substance civilization can be divided into Six Ages, which is the theory of six eras, as illustrated in Figure 1. However, the paper mentioned above [1], we did not discuss the Nanomaterials Age; therefore, the subject of the current paper is the Nanomaterials Age.

The following questions will be addressed in the following:

- What is the developmental history of nanomaterials?
- What was the evolutionary process of nanomaterials during the Silicon Age?
- Why has the world entered into the Nanomaterials Age?
- When did human society enter the Nanomaterials Age?

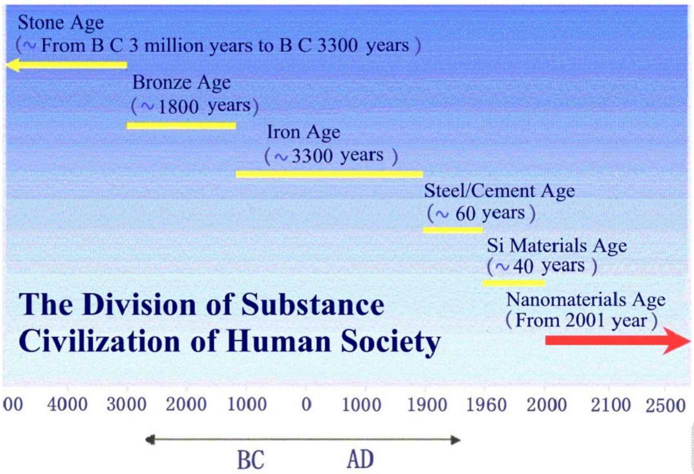

Figure 1: The proposed division of substance civilization in human society.

2.0 Framework of the History of Nanomaterials

Before discussing the specific contents of the Nanomaterials Age via the three standards of a typical material, we will analyze the history of nanomaterials briefly. The development of manmade nanomaterials can be traced back to ancient times. Additionally, this history can be divided into four stages: the budding stage, which occurred from ancient time to 1959; the initial preparation phase, which occurred from 1960 to 1990; the rapid development stage, which occurred from 1991 to 2000; and the industrial and commercial practical stage, which began in 2001 and continues to the present.

2.1 Budding Stage

During the budding stage of nanomaterials, humankind produced nanomaterials using very simple methods with rare applications that appeared to originate in ancient China. Specifically, these materials were carbon black, a black pigment and Chinese ink, which is one of The Four Treasures of this study. In October 1982, Chinese archaeologists discovered a house base that was built 5,000 years ago from the site of the advanced Yangshao culture located in the Gansu Province of China. Further, findings included pictures that were drawn on the ground with black pigment, which the laboratory in Gansu Province Museum identified as black carbon [2]. This type of carbon black was manufactured using pine soot, which indicates that the ancient Chinese understood how to make carbon black for making black pigment found prior to 5,000 years ago.

Chinese ink is very famous and the ancient Chinese knew how to make it with carbon black for several thousand years. This knowledge was identified by a Chinese ancient poem from the famous poet Cao Zhi (192~232 A. D.) who was the son of Cao Cao, a famous ancient Chinese politician and strategist. The first two sentences of the poem are “Chinese ink was produced by Pine Smoke; Chinese Brush was manufactured from rabbit hairs.” Of course, the ancient Chinese did not know, at that time, that the carbon black they used was a nanomaterial.

However, what is known is that extensive amounts of carbon black have been produced worldwide to enhance the strength and wear of rubber and in the manufacture of the black pigment, which was produced after the 20th century. We now know that carbon black is a nanomaterial because the standards of carbon black, also called an ASTM standard (N110~N900), used the size of the nanoparticles to define the grade of carbon black. The first number in the standard, N110~N900, represents the 10 number ranges of nanoparticles; for example, N110 represents that the average size of carbon black particles is about 15nm. In 1951, Känzig observed the first polar micro area with a size of 10～100nm in $BaTiO_3$ materials, which indicates that people began studying nanomaterials via experimentation [3]. The budding stage lasted a very long time, as the reorganization of nanomaterials was very shallow and limited as people gradually used these materials during this period.

One important event as when Nobel Prize winner, Richard Feynman, delivered a classical speech "There is plenty of room at the bottom" at the CIT on December 9, 1959 [4], where he suggested the end of the budding stage of nanomaterials. In this famous speech, Feynman predicted and that nanomaterials and technology, as well as their application, would be very useful for various aspects. As a theoretical physicist, he was able to make such a wise prediction near a half century early. However, mainstream scientists did not respond to his proposal, rather they took a suspending point of view, which did not change until around 1990.

2.2 Initial Preparation Phase

The initial preparation phase lasted 30 years. In general, the development of nanomaterials during this period faltered; only a few scientists conducted fragmented, decentralized research because, during this phase, mainstream scientists still did not participate in this field of research. In 1963, Ryozi Uyeda et al. obtained clean super microparticles and studied their structures with an electron microscope [5]. In 1970, J. C. Benjamin invented the Mechanical alloying (MA) process to manufacture nanopowders [6], which has become an important method for producing nanopowders today.

During the 1980s, researchers conducted more work on nanomaterials. In 1985, Kroto, Smalley, and Curl discovered C_{60}, which opened a new research field and gained them the Nobel Laureate in Chemistry 1996 [7]. With C_{60}, the carbon nanotube (CNT), discovered in 1991, and other relative carbon nanomaterials became important nanomaterials. Another important event during this period was the discovery of the Giant Magnetic Resistance (GMR) effect using Fe/Cr/Fe nanomultilayers by Albert Fert et al. at Paris-Sud University, France in 1988 [8]. Two years prior, Peter Grünberg's research group, at the Jülich KFA Institute, Germany, studied antiferromagnetic coupling using the Fe/Cr/Fe nanosandwich structure [9]. Since then, GMR nanomaterials promoted hard drives and, following, computers rapidly developed; Fert and Grünberg became Nobel Laureates in Physics in 2007 [10].

Van Wonterghem, from the Technical University of Denmark and their colleagues from England, manufactured amorphous alloy nanopowders via thermal decomposition in 1985 [11]. This research resulted in an economical way to produce nanopowders.

2.3 Rapid Development Stage

Following the budding and initial preparation phases, nanomaterials entered into a rapid development stage from 1991 to 2000. Four obvious marks characterized this stage. First, by this time, mainstream scientists joined the research of nanomaterials and technology. Second, the papers and patents of nanomaterials developed very rapidly. Specifically, the number of papers and patent applications increased from a few hundred in 1991 to 7,000 in 2000 [12] worldwide, an increase of more than 10 times. Third, the first international conference of nanoscience and technology was held in Baltimore, MD in July 1990. Further, the disciplines, Nanomaterials Science and Nanobiology, were proposed at the beginning of this period and special magazines, such as *Nanostructured materials* and *Nanoletters* were established. These activities indicate that the academic status of Nanomaterials disciplines was firmly established during this phase. Fourth, the so-called Nano-"hot" appeared during the final few years of this phase. The main indicators of this event were that investments only from government(s) to nanomaterials and nanotechnology rapidly enhanced, from US $116 and US $432 million in 1997 to US $270 and US $825 million in 2000, respectively as well as visible growth around the world [13]. Of note, this does not include risk investments made from private companies. In addition, the main countries, following the United States, created their own National Nanotechnology Initiatives (NNI) for the rapid development of nanomaterials and nanotechnology.

2.4 Industrial and Commercial Practical Stage

By the turn of the century, nanomaterials entered into an industrial and commercial practical stage. Further, the USA wanted to maintain its hegemonic position in nanomaterials and nanotechnology to realize the benefit for military and economic status. Other major countries, of course, do not want to lag behind, rather want to maintain their benefits in leading science and technology. Therefore, the degree of tension and competition is fierce. Further, some of the main characterizations of this stage will be discussed in the following.

3.0 Why Has Human Society Entered the Nanomaterials Age?

The main reason for suggesting that the present age of human society has entered the Nanomaterials Age is because nanomaterials and nanotechnology affect societies worldwide, comprehensively and deeply. After established its academic status, the development of Nanomaterials began to affect the world's economies, science and technology, military, and human life. Today many new research institutions are built specifically for the research of nanomaterials and nanotechnology. Additionally, many scientists, whose focus was on other research fields prior to this time, especially many young scientists, have converted to the research of nanomaterials and nanotechnology. Many private companies and factories have also joined the rank of manufacturing nanodevices and nanoproducts. For example, nanopowers, nanowires, CNT, and other carbon nanomaterials, nanofilms materials and nanobulk materials are been prepared and researched deeply within universities and research institutions and are being produced by many companies and factories. The impacting depth and breadth of nanomaterials and nanotechnology have impressed us deeply.

Today's nanoscience is not limited to its own field but extends to nearly all other macro disciplines. Porter and Youtie (2009) studied the relationship between nanoscience and nanotechnology and other disciplines of science and technology [14]. Their main results are shown in Figure 2. As illustrated in this figure, the size of each node is proportional to the number of nanopapers published in journals in each subject category during the period January–July 2008.

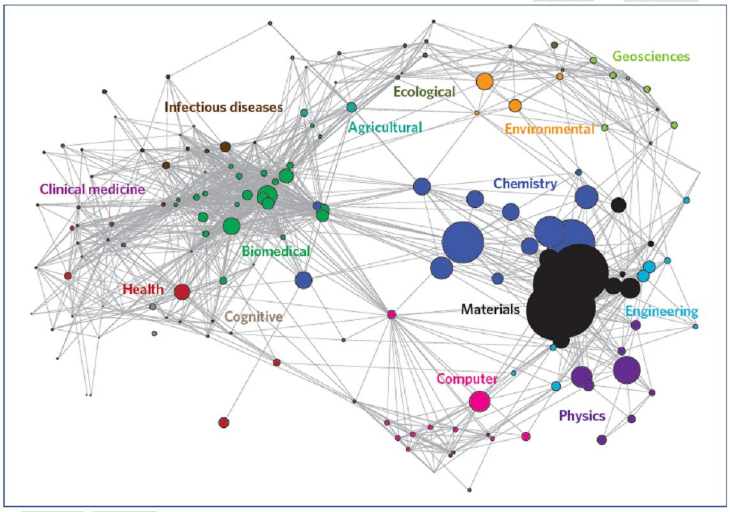

Figure 2: The position of nanoscience and nanotechnology over a base map of science. Location on the axes in this Kamada–Kawai algorithm representation has no inherent meaning: the connecting arcs and proximity reflect similarity based on cross-citation patterns, reinforced by coloring to reflect the clustering of subject categories into macrodisciplines.

The macro disciplines included in the figure are Materials science (50), Chemistry (44), Physics (11), Biomedical Sciences (9), Engineering sciences (7), Computer Science (3), Clinical Medicine (3), Environmental Science & Technology (2), Agricultural Sciences (1), Infectious Diseases (1), Geosciences (1), Ecological Sciences (< 1), Cognitive Sciences (< 1), Health (< 1) and Business & Management (< 1). The figures in parentheses are the percentage of nanopapers in each macro discipline. Two points can be seen from the figure. First, nanoscience has entered and penetrated all macro disciplines, including social sciences such as Cognitive Science and Business & Management. Second, the papers in nanoscience and nanotechnology account for 50% of the total number of articles in the Materials and Chemistry macro disciplines. In other words, nanoscience and nanotechnology have occupied a pivotal position in these macro disciplines.

It is interesting to note that many fundamental phenomena and processes of nanomaterials, which are very different from normal bulk materials, are newly discovered [15]. Some phenomena and processes include the following: decrease or increase in melting point; decrease in Debye temperature; increase in thermal expansion coefficient; enhance strength and toughness; display super plasticity, photoluminescence, and electroluminescent; magneto-optical Kerr effect; resistivity increase; increase in magnetic movement per atom and a decrease in the number of atoms from the bulk value; decrease in Curie temperature; enhancement of coercivity; and the discovery of GMR [16]. These new phenomena and discovery of various properties of these nanomaterials are different from common bulk materials because of their size. It is difficult to imagine that the corresponding bulk materials have similar phenomena and properties.

4.0 Large investments and huge markets of nanomaterials and nanotechnology

In addition to the mentioned reasons for the significant effects of nanomaterials, the following data are also proof. Using statistical data [17,18], Figure 3 was created. As seen in this Figure, global investments in nanotechnology R&D from governments were minimal prior to 1997. However, these investments increased annually from 1997 to 2000, but the increase was slow at first and picked up pace by the turn of the century. In the USA, investments increased from US $465 million in 2001 to US $1657 million in 2009, a 3.6 fold increase during these 9 years [18]. Worldwide, investments increased from US $1,534 million in 2001 to US $4,200 million in 2005, a 2.8 fold increase in 5 years. It must be pointed out that this investment was from governments and the figure does not include private venture capital. This is the ample evidence that nanoscience and nanotechnology are important and promising, which is why people must give generous financial support.

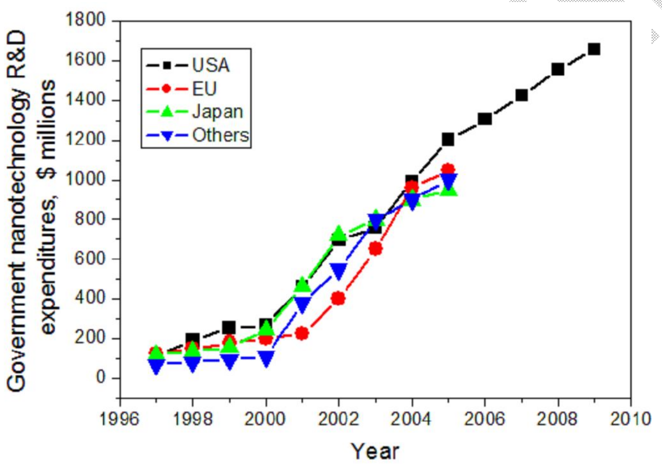

Figure 3: Government nanotechnology R&D expenditures since 1997.

The number of Nanoscale Science and Engineering (NSE) patents, worldwide, increased from 5,884 in 2000 to 8,802 in 2004, which is a 70% increase [19]. The number of NSE papers published in top 20 journals increased from 3,790 in 2000 to 5,776 in 2004, a 52% increase. The ratios of the NSE papers to all papers from top 20 journals increased from 10% in 2000 to 14% in 2004.

The global market size of nanomaterials and nanotechnologies totaled approximately US $7 billion in 2002 and, according to a leading research and advisory firm, Lux Research, more than US $32 billion in products that incorporate emerging nanotechnology were sold in 2005 [20]. That is to say, the global trade volume of nanomaterials and nanotechnologies has increased three times during a 3-year period.

5.0 A long period of human history will be affected by nanomaterials and nanotechnologies

Is the effect of nanomaterials and nanotechnology on the world temporary? No! Nanomaterials and nanotechnologies will affect the world for a long time, at least for several decades or more. By 2015, products that incorporate nanotechnology will contribute to between US $1 trillion to US $3 trillion [21], which is equivalent to between 10% and more than 30% of the value of world exports in 2005. These estimates are based on a broad industry survey and analysis conducted in the Americas, Europe, Asia, and Australia. What a huge industry we will have! Nanomaterials and nanotechnologies will clearly be strategically important and will provide both evolutionary and revolutionary displacement of existing products, processes and materials. The growth in global trade means that the products and processes of nanomaterials and nanotechnologies will extend across national boundaries and will almost invariably have a global impact.

Even more interesting is that M. C. Roco identified four distinct generations in the development of nanotechnology products that will span until 2020 [22]. The first generation is Passive Nanostructures (2000-2005). During this period, products will take advantage of the passive properties of nanomaterials, including coatings, nanoparticles, nanostructured metals, polymers, ceramics etc. The second generation is Active Nanostructures (2005-2010). Active nanostructures change their state during use and respond in predicable ways to the environment around them. Products will include 3D transistors, amplifiers, targeted drugs, actuators, adaptive structures, etc. The third generation is Systems of Nanosystems (2010-2015). In this stage, nanoproducts will be assembled and include 3D networking and new hierarchical architectures, robotics, and evolutionary systems. The fourth generation is Molecular Nanosystems (2015-2020). This stage will involve the intelligent design of molecular and atomic devices and lead to unprecedented understanding and control over the basic building blocks of all natural and manmade things. The products will emerge as functions, as M. C. Roco foresees that they are "multifunctional molecules, catalysts for synthesis and controlling of engineered nanostructures, subcellular interventions, and biomimetics for complex system dynamics and control" [22].

6.0 Only nanomaterials and nanotechnologies can help promote industries to solve problems and move forward

All industries experienced a high degree of development until the end of the Silicone Materials Age. However, many question how to develop these industries further and benefit human substance civilization during a more brilliant stage? This is a very serious issue placed before of the people of the world and advanced people, including scientists, are now thinking about and practicing them. For example, people have found direction in solving problems and achieved positive results because of the development of nanomaterials. Below we will illustrate some examples using events of some industries.

During the Silicone Materials Age, transistors and integrated circuits (ICs) occupied a pivotal position because the computer, IC products, Internet, mobile phone, etc. are all closely related to the development of transistors and IC. In fact, IC depends on the transistor. Here we use Intel CPU as an example to illustrate that the evolution from bulk materials to nanomaterials is an inevitable process of development; therefore, as the development of CPU can move industries forward. Table 1 shows the development of Intel CPU. This table is divided into three regions: the upper area in black color (region 1), the middle area in red (region 2), and the lower area in yellow. As seen in region 1, the manufacturing process for transistors decreased from 10 micron in the first Intel processor 4004 in 1971 to 0.13 micron in the Intel® Pentium® 4 Processor in 2001. We call such evolution a minimization process [23]. As with minimization, the transistors in CPUs increased from 2 300 to 55 million, which increased 239 thousand times over the past 30 years. Additionally, the properties of the CPU have greatly improved and the famous Moore's Law remained valid during this entire period [24]. Of note, this still belongs to the bulk materials although the size of materials has decreased to a fraction of one micron.

The problem is how to develop this further? Will Moore's Law remain valid in the future? Can the obstacles to development be overcome? Such problems were argued fiercely among scientists and engineers as well as others. Finally, scientists and engineers have overcome such problems and ceased the debate by developing materials from bulk materials to nanomaterials and technology from macro technology to nanotechnology. For example, scientists and engineers created nanotransistors to conquer such difficulties [25]. Region 2 in the table shows the evolution process of the Intel Nano CPU, which is based on nanotransistors. The manufacturing process for transistors decreased from 90 nm in 2005 to 22 nm in 2012. As such, the Intel Nano CPU in the region of nanomaterials and nanotechnology developed normally until recently. Finally, region 3 shows the roadmap of the Intel CPU from 2014 to 2022. The manufacturing process for transistors will decrease from 16 nm in 2014 to 4 nm in 2022. Even though the size will reduce to 4 nm, the region is still in the nanometer range. Further, many scientists and engineers believe that it will be true and will be carried out because it is not difficult to predict based on existing nanotechnology and its development.

Of course, people may know that the greatest atom in the Periodic Table is Cs, with radium of 0.26 nm. Therefore, a size of less than 1 nm belongs in the atomic range, not the nano range. From region 3 in Table 1, the Intel Nano CPU will be beyond the nano range and enter the atomic range soon after 2022. Clever people, therefore, might ask how the Intel Nano CPU will develop further after that time. Will Moore's Law maintain its continuity? Currently, we really do not know how to answer these questions. However, there are two points worth noting. Firstly, Moore's Law cannot remain valid forever because it is only an empirical law, not a natural regularity. Moore himself has noted this point many times. For example, Moore said "The important thing is that Moore's Law is exponential and no exponential is forever… But we can delay "forever"" [26]. Secondly, advanced scientists are studying other option than nanotechnology, for example, molecular electronics for the further minimization of electronic elements.

Table 1: The development of Intel CPU.

Intel processor	Intro date	Mfg. process / Transistors	Transistors	Clock speed	Addressable memory
4004	Nov-1971	10 micron	2 300	108 KHz	640 Bytes
8080	Apr-1974	6 micron	6 000	2 MHz	64 KB
8088	June-1979	3 micron	29 000	4.77-8 MHz	64 KB
Intel 386™ SX processor	June-1988	1.5 micron	275 000	16-33 MHz	16 MB
Intel 486™ SX processor	Sep-1991	1 micron	900 000-1.2 million	16-33 MHz	4 GB
Intel DX2™ SX processor	March-1992	0.8 micron	1.2 million	40-66 MHz	4 GB
Intel DX4™ SX processor	March-1994	0.6 micron	1.6 million	75-100 MHz	4 GB
Intel® Pentium® Processor	March-1995	0.6-0.35 mivron	3.3 million		
Intel® Pentium® Processor with MMX™ Technology	Oct-1996	0.35 micron	4.5 million	166-233 MHz	4 GB
Intel® Pentium® III Processor	Feb-1999	0.25 micron	9.5 million	450-600 MHz	4 GB
Intel® Pentium® 4 Processor	Nov-2000	0.18 micron	42 million	1.3-2 GHz	4 GB
Intel® Pentium® 4 Processor	Aug-2001	0.13 micron	55 million	1.8-3.4 GHz	4 GB
Intel® Pentium® 4 Processor Extreme Edition	Feb-2005	90 nm	169 million	3.6-3.8 GHz	64 GB
Intel® Pentium® Processor Extreme Edition 965	Jan-2006	65 nm	376 million	3.73 GHz	64 GB
Intel® Core™ 2 Extreme quad-core QX6800	Apr-2007	65 nm	582 million	2.93 GHz	64 GB
Intel® Core™ i7-975 processor Extreme Edition	June-2009	45 nm	731 million	3.33 GHz	—
Intel Westmene family processor	Started production, Expected Q2 2010	32 nm	?	?	?
?	Volume Manufacturing Stage 2012	22 nm	?	?	?
?	Expected 2014	16 nm	?	?	?
?	Expected 2016	11 nm	?	?	?
?	Expected 2018	8 nm	?	?	?
?	Expected 2020	6 nm	?	?	?
?	Expected 2022	4 nm	?	?	?

This is also the case for the hard disk drive (HDD) of a computer. From the first IBM HDD RAMAC in 1956 to the Seagate Barracuda XT 2TB SATA 6 Gbit/s Hard Drive released in September 2009, the store capacity increased from 4.4 MB to 2 TB, an enhancement of 455 thousand times. Additionally, the area density of these disk has increased from 2 Kb/in^2 = 2×10^{-6} GB/in^2 in the first RAMAC hard drive to 2 Tb/in^2 in the Seagate Barracuda XT 2TB Hard Drive, an increase of 1×10^9 (1 billion) times. It is obvious that this minimization also drew data storage and HDD forward rapidly [27]. When the bulk magnetic recording materials (magnetic resistance, MR) hindered the advance and development of data storage and HDD, nano magnetic recording materials (giant magnetic resistance, GMR) and technology (changes in longitudinal recording method to Perpendicular Recording Technology) helped overcome the difficulties. As for future developments, people are thinking of ways, other than magnetic recording, to explore different avenues, such as holographic data and atomic storage [28].

Nearly everyone knows the importance of the energy industry. However, there are two very serious issues that plague fossil energy sources (i.e., coal, oil and natural gas) presently used. These fossil energy sources are not all renewable energy and they will be exhausted in the near future. Further, many present disasters on earth (e.g., greenhouse effect, global warming, great floods, droughts, etc.) are all caused by burning these fossil energy sources. Therefore, people are looking for renewable energy sources to solve such problems. Much renewable energy has been studied and can be used to address these issues. For example, solar energy is a promising renewable energy because of it is inexhaustible and very clean and does not cause negative side effects. However, the energy conversion efficiency (ECE) of bulk single crystal silicon is only up to 11%, to date [29]. The lower ECE results in higher prices for solar cells; therefore, obstructs the progress and widespread application of solar cells. Further, the Carnot limit on the conversion of sunlight to electricity is 95%, as opposed to the theoretical upper limit of 40.7%, for a single junction cell [30]. The ECE of solar cells with nanomaterials could be up to 40-60% [31]. As such, scientists are studying various respects to enhance the ECE of nanosolar cells; the results are very promising.

The automobile is an important indicator of advanced development for human substance civilization. However, cars have two fatal flaws. The first is that they emit greenhouse gases. Of note, strategies to cut global carbon emissions were the only agenda item during the UN Copenhagen climate summit. The second flaw is catastrophic car accidents. Forty thousand people in the USA and more than eighty thousand people in China have been killed in car accidents every year to date. People are sure that, if nanomaterials and nanotechnology are widely used in cars, these serious problems could be solved gradually. In fact, nanomaterials and technology have a wide range of applications in the automobile industry. From internal to external, from the engine to the tires, from the structural to the decoration materials, and from lighting to protective paint, nanomaterials can be used in the automobile [32]. In addition, the worthy achievements and progress must be carried out.

Finally, we would like to say some words about the military industry concerning nanomaterials and nanotechnology. As an example, we only mention the so called “Super Soldiers Plan” from the USA MIT's Institute for Soldier Nanotechnologies (MIT's ISN) and the Center for Nanotechnology from NASA Ames [33,34]. The ISN established seven teams that conducted multidisciplinary research in the synthesis and processing of nanomaterials to design a soldier system of the future. They believed that nanomaterials could provide future soldiers with super strength, protection against bioweapons, and even a way to communicate covertly. What is the progress? From some of the information that has been exposed, researchers have made considerable achievements in many aspects, such as a fluid separator with smart surface [35], nano-scale armor [36], water and microbe-resistant fabric [37], increases in detection sensitivity [38], portable 'lab on a chip,' which could speed blood tests for soldiers [39].

In a word, only the nanomaterials and nanotechnologies that can help existing industries to overcome their facing difficulties is to become more efficient and competitive, gain advanced knowledge and emerging skills, and develop and produce unprecedented products and medicines that could not have been realized without the existing knowledge and tools. With nanomaterials and technologies being widely used in industry, people can expect emerging industrial sectors that have never been seen in the past.

7.0 Any other materials (steel or silicon) cannot replace the nanomaterials to produce new tools and devices

It is of particular importance that nanomaterials themselves or the tools, devices and products manufactured by nanomaterials cannot be replaced by any other non-nanomaterials or their products. A large number of instances illustrate this point. However, we will only cite a few examples. First, nanoparticles could be used to seek out cancer cells and then release an attached drug. Second, a nanoelectromechancial device, embedded into the construction material, could sense when the material is under strain and release an epoxy to repair ruptures. Third, a layer of nanomaterial might respond to a situation that where there is not light by emitting an electrical charges to power an appliance. Finally, bulk silicon materials cannot do all of these and steel and cement are even more powerless.

8.0 When did human society enter the Nanomaterials Age?

We are sure that the Nanomaterials Age started at the beginning of the new century, in 2001. Some of the reasons and most of the data indicating this have been mentioned above; however, we still would like to represent them in a more concise and clear way.

Nanomaterials and nanotechnologies entered into their industrial and commercial practical stage around 2001. The conditions that made this stage possible were twofold. First, the advances in characterization facilities that emerged during this time enabled scientific understanding of the structure of nanomaterials. Characterizing the structure of nanomaterials was very important because only materials that are characterized as being on the nano scale are considered real nanomaterials. In fact, besides characterizing the structure of materials, many physical, chemical, and biological properties for characterizing nanomaterials should be conducted. More particularly, the characterization of nanomaterials on toxicology studies and sustainable energy production should be given more attention [40-42]. It is interesting to note that in 2008, MINChar Initiative proposed the parameters for the "Recommended minimum physical and chemical parameters for characterizing nanomaterials on toxicology studies" [43]. Today, nanomaterial characterization tools, such as Transmission Light Microscopy (TLM), Near Field Optical Microscopy (NFOM), Scanning Electron Microscopy (SEM), Transmission Election Microscopy (TEM), Scanned Probe Microscopy (SPM), Scanning Tunneling Microscopy (STM), Atomic Force Microscopy (AFM), and Magnetic and Electric Force Microscopy (MFM & EFM) have been manufactured and developed. Simultaneously with the development of improved instruments for characterizing nanomaterials was the second enabling condition, which advanced fabrication facilities. Further, industrial manufacturing capabilities greatly improved the ability to manipulate materials at the nanoscale. Particularly in the area of electronics and photonics, one saw major advances leading to computer and communication devices with awesome functionality, storage capacity, and capabilities.

President Clinton announced formally the NNI of USA at CIT on January 21, 2000, which became its first act in the development of science and technology in November 2000. Following the USA, main countries throughout the world enacted and implemented their own NNI one after another in 2001 and 2002. Beginning with the new century, the world sounded the bugle to advance nanomaterials and nanotechnologies. For example, global investments for nanotechnology R&D form governments reached US $15.35 billion in 2001.

The so-called nanomaterials and nanotechnologies revolution opened and developed new markets. Further, worldwide nanomaterial and nanotechnology revenues were US $5 billion by the end of 2000, which was roughly comparable in size of the biotechnology sector [20], yet far less than the US $204 billion worldwide semiconductor revenues by the end of 2000 (Total Semiconductor World Market Sales & Shares 1982-2005). However, the nanotechnology market is believed to be growing more than twice as fast as both the biotechnology and semiconductor industries. Therefore, by 2015, the anticipated worldwide nanomaterial and nanotechnology revenues will approach US $2.6 trillion, or 15%, of manufacturing output in that year as suggested by Lux Research [20], which is far more than the estimated US $520 billion worldwide semiconductor revenue [44]. As this point, the Silicon Age will be completely immersed in the glorious Nanomaterial Age, just as the Steel/Cement age was shrouded by the brilliant Silicon Age after 1960. Such change in the various ages of human society should not bring any sadness, even for those who like nostalgia, because the new Nanomaterials Age brings more brilliant substances, cultural civilization, and a higher quality of life. Here we can just use an old Chinese proverb: "Why not do it!"

9.0 Conclusion

Humankind's use of nanomaterials can be traced to ancient times. The developmental history of nanomaterials has been divided into four phases. The skeleton of every stage was described and discussed above. Additionally, the evolutionary process of nanomaterials during the Silicon Materials Age was analyzed and discussed. The reasons that the world has entered into the Nanomaterials Age are also analyzed and discussed. Based on this information, one can see that the Silicon era inevitably bred the Nanomaterials Age. The substance civilization of human society entered into the Nanomaterials Age at the beginning of the new century. We have proved the advent of the Nanomaterials Age with indisputable facts. Further, the proposed six-age systems theory on the division of the substance civilization of human society, therefore, has a complete exposition. People can believe with sufficient reasons that nanomaterials will bring the substance and culture civilization of humankind to an unprecedented level that has never before appeared, which will enhance the quality of life of mankind. Let us hold high our both hands to welcome her arrival! Let us use our efforts and sweat to water and urge its smooth and healthy development of this beautiful Nanomaterials Age! Let the Nanomaterials

Age become a truly harmonious and happy home of human life! Finally, we must point out that nanomaterials have not only positive effects, which resulted in the second industry revolution, but also have potential negative health and environmental impacts that could bring harm to our lives [45]. This is the duplicity of nanoscience and nanotechnology [46]! However, the negative effects of nanomaterials were not discussed in this paper because this was not the task of this paper; however, it is necessary to note this obvious point.

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