Characterization and Application of Nanomaterials (2022) Volume 5 Issue 1
doi:10.24294/can.v5i1.1680

REVIEW ARTICLE

Nanotechnology, architecture and art

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ABSTRACT

In the past three decades, nanotechnology has attracted extensive attention. People have many expectations on the utilization of nanotechnology in medicine, but unfortunately, these expectations are unlikely to be realized. In the field of nanotechnology, the niche for building commercial products has not been developed yet. However, metal nanoparticles have attracted people's attention since ancient times because of their optical properties, which are very different from those of bulk metals. By understanding the origin of these optical properties and using current technology, these nanoparticles can be manipulated to build a palette. Using micro measurement equipment, the palette can be printed with very good resolution.

Keywords: Metal Nanoparticles; Plasma; Photoprinting

ARTICLE INFO

Received: 7 January 2022
Accepted: 26 February 2022
Available online: 9 March 2022

1. Introduction

In the past decade, the word "nanotechnology" has appeared on countless occasions, referring to great inventions that will change our lives. Unfortunately, we live in a world that is distorted by mass media transmission. We believe that the trivialization of the term nanotechnology is due to two basic factors: (1) after an important discovery, scientists' emotions confuse them and sometimes have high expectations for future applications; and (2) the media exaggerate the news coverage of this discovery. Therefore, the new discoveries realized by science through dissemination to others distort the meaning of social life and produce high expectations that are often difficult to achieve. At the end of the Second World War, the great potential of nuclear energy emerged. It is generally believed that nuclear energy will solve human problems in this regard, but it didn't happen. In the 1980s, when the high-temperature superconductor was discovered, the superconductivity of this material was higher than the temperature of liquid helium, higher than -269 °C. It was also said that the energy problem would be solved to a great extent: in our daily life, the current of a conductor is expected to be maintained indefinitely, but this did not happen. However, it is undeniable that apart from its negative uses, nuclear energy is beneficial to people's lives in many ways. On the other hand, at more accessible temperatures, such as -196 °C, superconductivity has opened up a new research field. The same is true for nanotechnology. There is no doubt that nanotechnology is bringing great benefits to the fields of biomedicine, energy, environment, and photonics (aimed at replacing electronics).

Metal nanoparticles, due to their surface plasmon resonance characteristics, produce a very strong near nanoscale electric field at nano distance, making them high-sensitivity and high-resolution sensors in two-state systems and photonics[1,2].

In order to understand what we are going to write about architecture and art, we must first understand what nanotechnology is.

2. Nanotechnology

Nanotechnology originates from the understanding of nanostructures in nanoscience. From the perspective of size, the nanostructure is a collection of atoms or molecules, and its size is on the non-metrological scale (1 nm = 10^{-9} meters, 1000 times that of 1 micron). A cell with a size between 5 and 50 microns is tens of thousands of times larger than what we mean by nanostructures. However, nanostructures have always existed and been produced. But these structures were not understood until a few years ago. For nanoscience, the nanostructures that make up nanotechnology are those basic elements, whether atoms or basic crystal cells. In nanoscale aggregates, they show characteristics different from the mass properties we are used to in our daily life. Not all nanostructures show characteristics different from large volume structures, so these characteristics are not considered in nanotechnology. At present, however, nano-sized materials, whether or not they have properties different from those in large volume, are considered a part of nanotechnology products. In the field of architecture, there are few truly commercialized and large-scale nanotechnology products. This paper describes the real nanotechnology materials used in architecture and the materials currently being developed for printing.

3. Metal nanoparticles and plasma

Plasma is a new branch of science. The term was coined by a group of scientists at the California Institute of Technology in 2000[3]. Plasma refers to the surface plasma that produces light when being hit by metal particles. We know that light is an electromagnetic wave composed of oscillating electric and magnetic fields. When the electric field of the wave acts on the metal nanoparticles, the free electrons of the super surface metal oscillate with the electric field of the wave. Through some physical mechanisms, the nanoparticles absorb a large amount of light. At some wavelengths, this absorption occurs in a privileged form, which is called surface plasmon resonance. This phenomenon only occurs when the size of metal particles is much smaller than the wavelength of the incident light, from some nanometers to 100 nm, so it will not occur in a large volume of materials[4]. This particularity bestows these nanoparticles' interesting optical properties in nonlinear optics[5], photonics[6], and biomedicine[1,7].

Interestingly, this phenomenon leads to the absorption of metal nanoparticles in the ultraviolet and visible regions. In special cases, nanoparticles over 100 nm absorb in the infrared range of the electromagnetic spectrum[8].

4. Light and color

Light is an electromagnetic wave, which is part of the electromagnetic spectrum. The electromagnetic spectrum is very broad, including wavelengths ranging from picometers to kilometers. In this large range, light occupies the so-called visible region, which is a very small region of the electromagnetic spectrum. White visible light disperses through a prism and is separated into its component colors. This is because visible light consists of wavelengths between 380 and 780 nm, which are perceived by the eyes and detected as color in our brain. We know that the color of objects is caused by the different lengths they absorb and the different lengths reflected by other objects and detected by the eyes. Therefore, metal nanoparticles up to 100 nm absorb the visible light band and show a color that metals do not have in a large volume.

5. The wonderful world of color in metal nanoparticles

In the previous section, we have said that metal nanoparticles selectively absorb visible light at some visible wavelengths. Specifically, this absorption is carried out in some nanoscale to 100 nanoscale structures. In addition, nanoparticles can have different shapes. According to the size and shape of nanoparticles, surface plasmon resonance, when the light is absorbed to the greatest extent, can move and expand in the spectrum, so as to change the color. We know that if it absorbs blue light, the color will turn yellow. This is why the surface plasmon resonance wavelength of silver nanoparticles embedded in glass with a spherical diameter of about 10 nm is 380 nm and the width extends to blue. This is why these nanoparticles appear yellow. If the size and shape of these particles change, surface plasmon resonance can occur at higher or lower wavelengths, or can be expanded according to the situation to produce different colors. If the green color is absorbed, the color will be red. Another example is gold nanoparticles. If these nanoparticles are spherical, they are between 4 nm and 20 nm, and their surface plasmon resonance is 520 nm. Therefore, they have strong absorption of green, making them look red. If their size increases to about 90 nm, they will appear blue. Nanoparticles can have a range of bright colors depending on their shape and size. **Figure 1** shows a series of solutions containing metal nanoparticles of different elements of different shapes and sizes. When these nanoparticles are embedded in glass, they will show different colors according to the nanoparticles involved.

Figure 1. Metal nanoparticles in solution.
Source: José I. García Laureiro, isqch. Blog promotion of Institute of Chemical Synthesis and homogeneous catalysis Higher Scientific Research Council (CSIC) of the University of Zaragoza, Spain.

6. Design of nanodevices

The synthesis of metal nanoparticles can be carried out by chemical or physical methods. It is relatively simple to synthesize in an aqueous solution by chemical method. The color is really bright. As early as 1875, Michael Faraday already had the solutions. He first described these colors scientifically, referring to very small particles with optical properties different from large volume metals. One physical method is ion implantation. Through the particle accelerator, the required metal atoms are introduced into the dielectric one-to-one[9]. The obtained material is then treated at a high temperature and special atmosphere. **Figure 2** shows two different amounts of high-purity silica-implanted gold. These materials were obtained at the Pelletron Accelerator Laboratory of the UNAMA Institute of Physics.

Although the properties of metal nanoparticles had already be explained in the 19th century, the discipline of nanoscience and nanotechnology has only emerged recently after completely repeatable synthesis and analysis methods have been developed. This is the result of scientific and technological progress. The synthetic methods of these systems, both physical and chemical, have made great progress. Nowadays, people are designing the particles to be manufactured. If coupled with the extraordinary scientific instruments in the 20th century, a series of analytical methods would be able to produce microscale materials; this progress would usher in the nanoscale ear at a faster pace. For example, the emergence of nanoparticles expedites the development of ultra-high-resolution transmission electron microscopy. This technology enables us to view the location of nanoparticles and their atoms (**Figure 3**). On the other hand, really complex calculations have been carried out on desktop computers, so that they can simulate and predict what shapes correspond to surface plasmon resonance so as to determine its specific optical characteristics. This makes it possible to produce dispersible materials with very special properties.

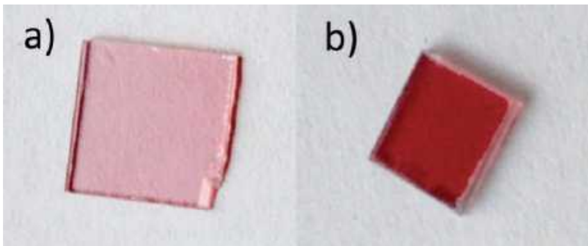

Figure 2. High-purity silica with spherical gold nanoparticles with an average diameter of 10 nm. (**a**) Low gold ion inflow. (**b**) High gold ion inflow. Source: authors' images.

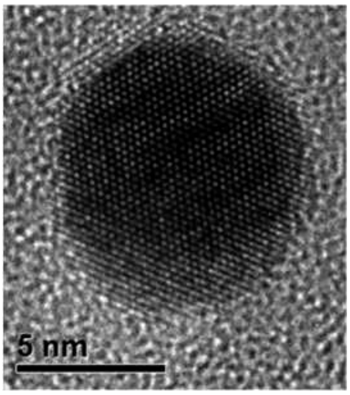

Figure 3. High-resolution transmission electron microscopy micrograph of gold nanoparticles in ion-implanted silicon. Source: authors' image.

Therefore, at present, science and technology allow the use of nanostructures to design, operate and, in some cases, build devices for different applications[10].

7. There is nothing new in the sun

Colored glass and colored glass beads have always attracted people. Humans have learned to make colored glass since ancient times. The main glass products are colored bead necklaces. As early as 1200 BC, Egypt had a blue or green transparent glass. Of course, it was also in Egypt people found out that adding metal oxides to molten glass would produce beautiful colors. However, the people who did glassblowing are Phoenicians. During the Roman Empire, the manufacture of glass products spread throughout the empire and Germany.

Figure 4. Likugo Rome Cup at British Museum. (**a**) Illumination on the observer's side. (**b**) Rear illumination relative to the observer. Source: Figures (a) and (b) were photographed by John Bode and Mary Ranran, respectively.

In ancient times, craftsmen were already utilizing nanotechnology in producing glass products with colors. An indisputable example is the beautiful Likugo cup in Rome. The cup was made in the 4th century AD, and its owner had been troubled by the influence of light on the cup for a long time. When illuminated from the observer's side, it shows green emerald (**Figure 4(a)**), and the glass looks opaque, but when illuminated from the back relative to the observer, it shows translucent and bright red (**Figure 4(b)**). The secret was discovered in 1990. Small fragments of the glass were analyzed by electron microscope. The results showed that the glass contained a very accurate mixture of gold and silver particles below 50 nm. Through the invention of this cup, we can deduce that knowledge of contemporary nanotechnology was practiced and utilized in manufacturing products in ancient times.

Perhaps, the most famous building of nanotechnology is the glass window of the Gothic cathedral. Gothic architecture originated in northern France in Normandy in the 12th century. It first spread to the kingdom of France, and then to the Holy Roman Empire. This new architectural style engendered a new form of buildings that were infused with different proportions of Romanesque and Gothic architecture styles: thinner and higher vaults. In order to withstand the thrust of the vault, the architects designed buttresses with stumps. The exterior wall has a huge gap, and the interior wall produces greater brightness. This gave rise to what is known today, the medieval glass art that embodies its colorful interior. The Holy Church in central Paris is a good example. The walls of this building, which was built in the early 13th century, were replaced by huge windows covered with glass (**Figure 5**).

Figure 5. Holy Church of Paris. Source: Photograph by B. Didier.

The bright indoor environment brings a very special effect to the atmosphere. Unlike the effect produced by a normal window, the window used in the building can let all the white light in the solar radiation pass through. These craftsmen, the original nanotechnology experts, know very well what to put in the molten glass and their proportions to obtain the whole color range of the glass. Even today, we still appreciate the richness of these works of art (**Figure 6**).

Figure 6. The glass windows of Cologne Cathedral. Source: Photograph by Jan van der Crabben.

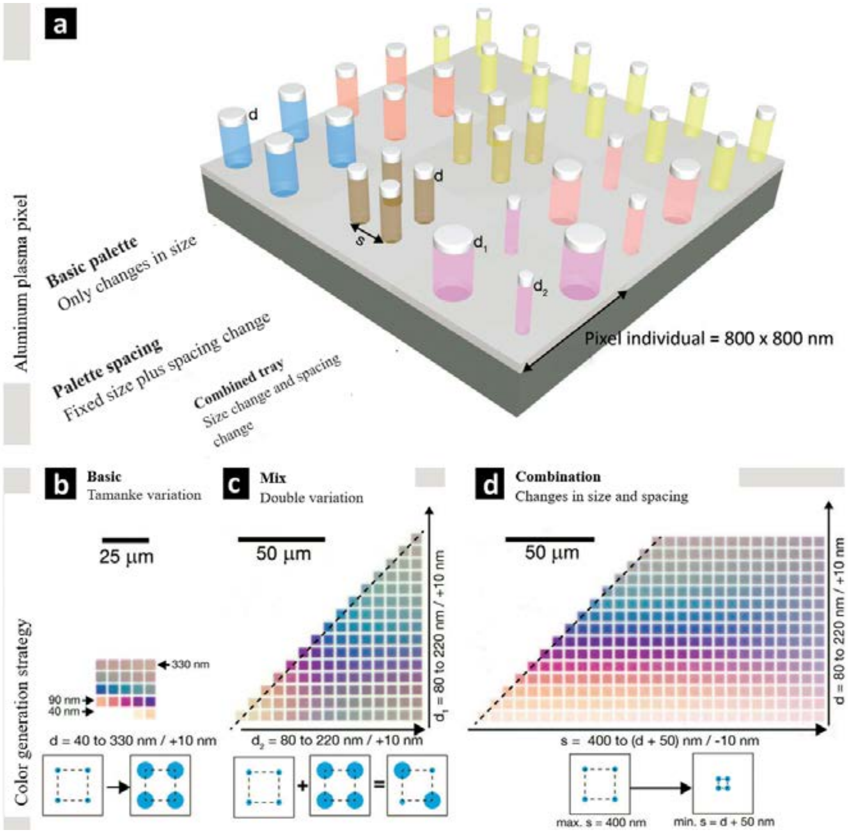

Figure 7. Schematic diagram of the plasma pixel configuration of aluminum nano disk: (**a**) different arrangement of nanodisk in size and spacing; (**b**) palette of the basic layout of nanodisk; (**c**) a hybrid palette that provides different sizes of nanodiscs with a spacing of one pixel; and (**d**) a palette that combines the size and spacing of nanodiscs into one pixel. Source: Adapted with the permission of Tan *et al*.[11].

8. Modern nanotechnology and color palette

The color image reproduction system uses filters and prisms to disperse light of different wavelengths. With the miniaturization of integrated devices, the research on the image sensor is growing exponentially. The pursuit of high efficiency, low power consumption, and small size poses a great challenge to the traditional system.

In the previous section, it was explained that the surface plasmon resonance of metal nanoparticles absorbs light and makes these nanoparticles reflect the light of a certain color. In 2014, scientists from several institutions in Singapore built devices containing specific arrangements of aluminum nanodisks of different sizes with different spatial arrangements[11]. In this way, they built plasma pixels to form a palette. Each pixel contains four nanodisks of different sizes to create a basic palette. By changing the distance between them and the size of the nanodisk, different colors and tones can be created and converted into the colors and tones of the palette. These nanostructures were obtained by forming nanocolumns on silicon substrate by electron beam lithography. Aluminium with a thickness of 20 nm was deposited on silicon substrate by electron beam lithography. The size of each pixel is 800 × 800 nm.

As shown in **Figure 7(a)**, the basic tray is composed of aluminum nanodisks with the same spacing but different sizes. Other colors and tones can be generated using the same size and different spacing. Finally, the palette is enhanced by a combination of size, space, and layout geometry. **Figure 7(b)** shows the arrangement of the basic tray, in which only the size changes, the disc diameter is 40 to 330 nm, the step diameter is 10 nm, and the fixed spacing is 400 nm. **Figure 7(c)** shows how the change in size is intertwined with the change in Di, where D in each pixel (two nanodisks of one size and two nanodisks of another size) = 80 to 220 nm, with each step of 10 nm. The fixed spacing on the same pixel is 400 nm, 800 × 800 nm, which enriches the palette. In **Figure 7(d)**, the color palette is formed by changing the size (d = 80 to 220 nm) and spacing (s = D + 50 to 400 nm) in steps of 10 and 20 nm, respectively, in the arrangement of four nanodiscs in 800 × 800 nm pixels.

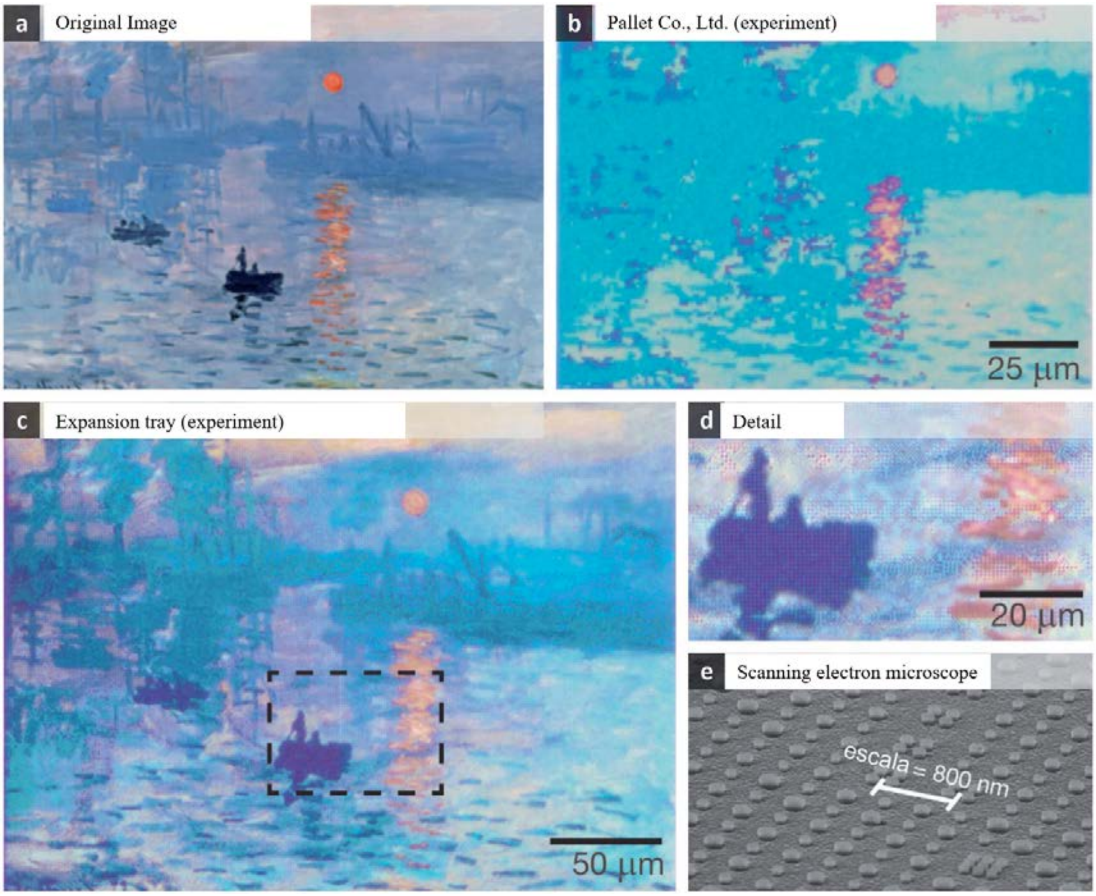

Figure 8. Using different strategies of plasma palette to reproduce Monet's sunrise painting: (**a**) reproduce the original as the input image; (**b**) copy using only the "primary plasma colors" palette; (**c**) use the extended palette to reproduce the painting more realistically; (**d**) enlarge the details in panel (c); and (**e**) scanning electron microscope micrograph that shows the pixels in different arrays of aluminum nanodisks. Source: Adapted with permission of Tan *et al*.[11].

These combinations of aluminum nanodisks in pixels produce plasma in the visible palette.

In order to show the versatility of their plasma palette contained in the microstructure, these scientists created photo prints of Monet's famous painting dawn. A copy of the original is shown in **Figure 8(a)**. In **Figure 8(b)**, printing is performed using a limited (basic) plasma palette. In **Figure 8(c)**, photo printing with a wider color range can be obtained using an extended palette (a combination of pixel and nanodisk size and spacing). The degree of repeatability is impressive for a micron device, as obtained in the described work. **Figure 8(d)** shows the details, and **Figure 8(e)** shows a scanning electron microscope micrograph of pixels with different arrangements of nanodisks.

Compared with their gold or silver counterparts, aluminum nanoparticles are very durable and much cheaper. Therefore, microdevices with these characteristics have a huge market prospect.

9. Conclusion

The optical properties of metal nanoparticles are very different from those of large-volume metal nanoparticles. It was first used to decorate objects and is now used as high-resolution photonic microdevices. From the perspective of architecture and art, the charm of color and the effect of light have always influenced mankind.

Conflict of interest

The authors declared no conflict of interest.

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