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SYNTHESIS METHODS AND PROPERTIES OF METALLIC NANOSTRUCTURES

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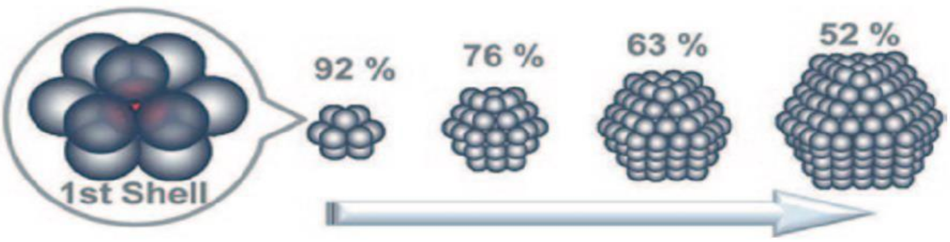
Abstract:

It is now well known that the size and shape of metallic nanostructures can significantly alter their properties. The large surface area to volume ratio of metallic nanostructures is the reason for a number of unique applications, especially in catalysis. Metallic nanostructures possessing LSPR in the visible wavelength range are typically metals with a negative real and small positive imaginary dielectric permittivity, such as gold, silver, and copper. Interest in the rational synthesis of metallic nanostructures with controlled sizes and morphology is based not only on their aesthetic appeal.

Keywords: Metal nanostructure, morphology, Au and Ag nanostructures, LSPR, photochemical, thermal decomposition.

Introduction

The rapid development of the synthesis of metallic nanostructures with controlled morphology has made it possible to discover their new properties [1]. It is now well known that the size and shape of metallic nanostructures can significantly alter their properties. One of the most well-known size-dependent properties of metallic nanostructures is their high surface area to volume ratio. Table 1 shows the relationships between particle size and the percentage of surface atoms for Pt nanocubes with a cuboctahedral shape [2-7].



Calculated sizes of cuboctahedral Pt nanoparticles and their corresponding surface atomic percentages (reproduced with permission from reference [reference number])

Table 1.

Number of shells	Number of surface atoms	Number of total atoms	Percentage of surface atoms (%)	Size of Pt nanoparticles (nm)
1	12	13	92	0.8
2	42	55	76	1.4
3	92	147	63	1.9
4	162	309	52	2.4
5	252	561	45	3.0
6	362	923	39	3.5
7	492	1415	35	4.1
8	642	2057	31	4.6
9	812	2869	28	5.1

It can be clearly seen that as the size of Pt nanoparticles decreases, a sharp increase in the percentage of surface atoms can be obtained. The large surface area to volume ratio of metallic nanostructures is the reason for a number of unique applications, especially in catalysis [3,4]. In addition to their size, the shape of metallic nanostructures also strongly influences their optical, catalytic, and magnetic properties. This section briefly presents the correlation between these properties and the morphology of metallic nanostructures.

The bright colors of Au and Ag nanostructures have fascinated people for millennia. These phenomena arise from localized surface plasmon resonance (LSPR). LSPR is the resonant collective oscillation of free electrons 1 in metallic nanostructures when irradiated with light. LSPR can lead to strong absorption, light scattering, and enhancement of the local electromagnetic field. Based on these characteristics, plasmonic nanostructures have found wide application in biological sensing and imaging, photothermal therapy, and solar energy harvesting [5].

Metallic nanostructures possessing LSPR in the visible wavelength range are typically metals with a negative real and a small positive imaginary dielectric permittivity, such as gold, silver, and copper. One of the remarkable features of LSPR is that its frequency and intensity strongly depend on the size, shape, and composition of the plasmonic metallic nanostructures. This provides an important method for adapting the LSPR of metallic nanostructures by synthetically tuning their structural parameters. For example, Figure 1.8 shows three types of metallic nanostructures with tunable LSPR properties:

Figure 1.8. Metallic nanostructures with tunable localized surface plasmon resonance (LSPR): a - Au nanorods with different aspect ratios, b – Au nanoshells with different shell thicknesses, 1 and c – Au/Ag nanocages with different compositions and shell thicknesses (reproduced with

permission from the reference, nanorods, nanoshells, and nanocages. Their optical properties can be controlled by adjusting the aspect ratio, shell thickness, and composition. Another feature of LSPR is that it is very sensitive to the refractive index of the surrounding 2 environment [6, 8]. Pronounced red shifts in the spectral position of the LSPR can be observed with an increase in the refractive index of the surrounding environment. Based on this property, LSPR has been used for ultrasensitive sensing.

Localized Surface Plasmon Resonance (LSPR) is a resonant collective oscillation of free electrons in metallic nanostructures when irradiated with light. LSPR can lead to strong absorption, scattering of light, and enhancement of the local electromagnetic field. This provides an important method for adapting the LSPR of metallic nanostructures by synthetically tuning their structural parameters. Consequently, the ability to generate metallic nanomaterials with well-controlled sizes, shapes, and compositions plays a central role in understanding the chemical and physical properties of metallic nanostructures. These methods can be implemented using either chemical or physical processes in the gas, liquid, or solid phases.

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