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Copper nanoparticles: Synthesis methods and its light harvesting performance

Farhana Parveen [a], Basavaraja Sannakki [a], Mohanrao V. Mandke [b,c], Habib M. Pathan [b,*]

[a] Department of Physics, Gulbarga University, Gulbarga 585106, India
[b] Advanced Physics Laboratory, Department of Physics, Savitribai Phule Pune University, Pune 411007, India
[c] National Defence Academy, Khadakwasla, Pune 411023, India

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ABSTRACT

The metallic nanoparticles have a unique optical property known as surface plasmon resonance (SPR) which can be utilized to enhance the light harvesting performance in solar cells. Efficiency of the solar cell strongly depends on various deposition methods, band structure, light absorption and electronic properties of the material being used. The noble metals (Au, Ag, and Cu) have the ability to support surface plasmon resonance and can be used to enhance the efficiency of a solar cell. Cu being cheap and more abundant in nature is being utilized on a large scale for the fabrication of the solar cells. This paper reviews the different chemical methods used for the deposition of Cu nanoparticles and their utilization in plasmonic solar cell.

Contents

1. Introduction

Nanoscience and nanotechnology involve the study and working with matter on an ultra-small scale. Nano refers to a nanometer (nm). One nanometer is a millionth of a millimeter or about one eighty thousandth the width of a human hair. Nanomaterial is of great scientific interest as they are effectively a bridge between bulk materials and atomic or molecular structures. A bulk material should have constant physical properties regardless of its size, but at nanoscale this is often not the case. The properties of the materials change as their size approaches the nanoscale and as the percentage of atoms at the surface of a material becomes significant. For bulk materials larger than one micrometer the percentage of atoms at the surface is less, relative to the total number of atoms of the material. Therefore these interesting and sometimes unexpected properties are partly due to the surface that dominates in nanoparticles, which is not the case in bulk materials.

Interest in metal nanoparticles is driven which exhibit novel chemical and physical properties due to their small physical dimensions. Due to their small size and large surface area the metal nanoparticles have unique electronic, mechanical, magnetic

* Corresponding author.

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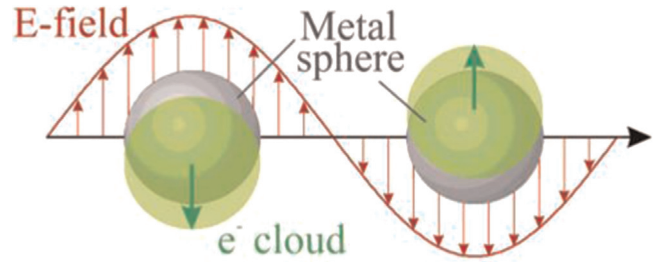

Fig. 1. Schematic of plasmon oscillation for a sphere, showing the displacement of the conduction electron charge cloud relative to the nuclei. Reproduced with permission from Ref. [5]. Copyright 2003 American Chemical Society.

and chemical properties that are different from those of bulk materials. For these reasons metallic nanoparticles have found applications in different fields such as electronic, thermal, catalysis, photonics, biosensors and optoelectronics [1–4]. In particular, nanoparticles of metals show an interesting optical behavior known as surface plasmon resonance as the nanoparticles diameter becomes comparable with, or smaller than the wavelength of incident light. This behavior depends upon the size, shape as well as dielectric environment of metal nanoparticles. Surface plasmon resonance is light induced collective oscillations of electrons in metal nanoparticles, which becomes localized due to the restriction of dimensions. When the light frequency is in resonant with collective oscillations of electrons, both strong absorption and scattering of incident light may occur, which is known as localized surface plasmon resonance (LSPR) [5] as shown in Fig. 1. The frequency of the LSPR is determined primarily by the physical parameters of metal nanoparticles (complex dielectric constant, dimensions and shapes), as well as the refractive index of the surrounding material. LSPR is expected to enhance the light harvesting performance in photovoltaic through scattering and local enhancement in electromagnetic fields [6,7]. The photovoltaic devices are bound to play a major role in addressing our future energy needs. The noble metals such as Au and Cu have the ability to support plasmon resonance in the visible wavelength region. For this reason these noble metals are the materials of great interest in the field of plasmonics for the number of applications where LSPR is used for enhancing the light absorption in metallic nanoparticles and thereby photovoltaic performance of the plasmonic solar cells.

Plasmonic solar cells have great potential to drive down the cost of solar power. The basic principle used for the functioning of plasmonic solar cell is scattering and absorption of light due to incorporation of metal nanoparticles in solar cells. The absorbed light can be used further to create more number of charge carriers; therefore the photovoltaic performance of the cell can be enhanced. So this property of the plasmonic solar cell can be utilized to improve the efficiency solar cells.

Generally for plasmonic solar cell noble metals such as gold and silver are being exploited despite their costliness. In this regard Cu is a plasmonic material that is more abundant and less expensive than Au and Ag and might constitute a potential alternative for the commercialization of plasmonic technology. In this paper we review a few chemical methods for synthesis of Cu nanoparticles and its utilization in plasmonic solar cell.

2. Plasmonic features of copper

Cu, with atomic number 29 and atomic weight 63.54, occupies the first position of subgroup IB in the periodic chart of the elements. Subgroup IB also includes Ag and Au; in fact, Cu shares many characteristics with these other noble metals due to its atomic and electron structure. It has a very high thermal and electrical conductivity. Pure Cu is very soft and malleable and it has a FCC crystal structure as shown in Fig. 2.

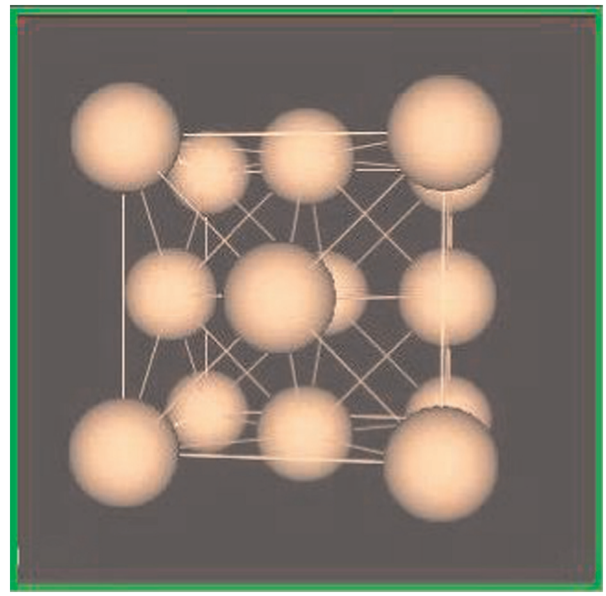

Fig. 2. FCC crystal structure of copper.

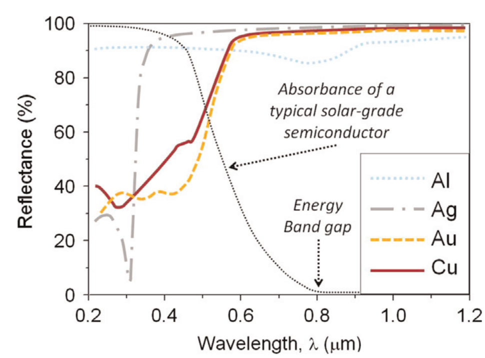

Fig. 3. Reflectance of selected metals as a function of wavelength. Reproduced with permission from Ref. [8]. Copyright 2013 The University of Western Ontario London, Ontario, Canada.

Cu is one of the most important materials in plasmonics. It offers many advantages over the other metals which support surface plasmon. In terms of plasmonics it is important to choose a metal that can support a strong surface plasmon at the desired resonance wavelength most particularly in visible region. The Cu nanoparticles undergoes oxidation and gives interband transition of d band electrons below 600 nm but can support the surface plasmon resonance in part of the visible range as compared to Ag and Au. The SPR wavelength for Au and Cu lie in the visible region (~500 nm for Au and ~590 nm for Cu), whereas for the Ag the SPR wavelength lies in both visible and IR region (~300–1200 nm). Fig. 3 indicates the trend of the optical absorbance of a typical solar-grade semiconductor [8]. Its optimal energy band gap for best AM1.5 solar efficiency is approximately 830 nm. The metals suitable for applications in semiconducting plasmonic devices have plasmon energy just above the semiconductor band gap energy. Therefore Au and Cu are optimized for applications in plasmonic solar cells. The Cu nanoparticles are preferred over Au nanoparticles because of their cost-effectiveness, but Cu is more prone to oxidation and contamination. Therefore care should be