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Role of Silver Nanocrystals in Printing Technology for Flexible Electronics and Wearable Health Devices

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Abstract

Researchers have been focusing on printed electronics as they are cheap, occupy small volumes, have very high speed and can be changed easily. Silver nanoparticle plays a key role in flexible printing at room temperature and other electronic applications. Use of nanoparticle ink enables to design wearable biosensor systems for health monitoring. Advances have been made towards a new generation of wearable devices that can fit themselves to the human body, not only help to identify and track physical activity of the wearer, but also provide communication capability which allows us to access data in real-time using another medium. This paper outlines the key role of silver nanocrystals as an ink used for flexible materials as well as the advances of wearable devices and their applications in electronics and medical field.

Keywords: nanoparticle, flexible printing, wearable devices, etc.

INTRODUCTION

In past decade nanotechnology has been steadily growing number of applications in almost every field especially in electronics and medicine as well. It still remains to see that to what extend nanotech will reshape these fields. Flexible, bendable and stretchable electronics are reaching into various sectors and are being integrated into a variety of products, including wearables and medical applications. A team of

Fig 1. A flexible supercapacitor

researchers in Singapore [1] has developed a flexible supercapacitor using ribbons of graphene as shown in figure 1. These have higher power density and longer life cycle but less storage time than standard capacitors. Such flexible components lead towards advance flexible electronic devices.

It is well known that metals transport electricity almost without any loss. Therefore use of metals cannot be avoided to develop nanoparticle ink. However, Gold nanoclusters have been known for decades, but researchers are attracted more by silver clusters since silver is a cheaper metal than gold and its optical properties are better controllable as compared to gold for applications. Nano clusters of silver are discussed in detail in this paper, that are very interesting from the theoretical point of view as they are big enough to possess the properties similar to that of silver metal and small enough to study their electronic structure. Silver nanoparticles possess properties that have many potential industrial applications, especially for the field of electronics and optics. Various properties such as optical magnetic, catalytic and electronic are sensitive to their shape and the size of the nanoparticles [2]. The nanoscale enables the surface tension and the ionic forces work against gravity and hence provide stability. Other phenomena like surface plasmon resonance, interaction with electromagnetic field [3], enhancement of diffusivity of the surface atoms also takes place which enables the sintering at very low temperature [4].

Silver not only offers conductivity but it is efficient and also stays cool. Since manufacturing is done at high temperatures therefore flexible substrates like plastics/ paper cannot be used as they might melt or burn. OSU scientists have introduced a micro reactor to create silver nanoparticles at room temperatures without any protective coating which can be immediately used for printing on almost any substrate with a continuous flow process. This enables the use of different substrates, for example: plastics, glass or papers which are flexible as well as stable. Therefore silver may be used in many electronic applications, such as printed circuit boards, solar cells, transparent electronics etc.

Use of nanoparticle ink enables to design wearable biosensor systems for health monitoring. These systems possess various small sensors, transmission modules and processing capabilities to provide low cost wearable for health and activity monitoring. Not only medical expenses are increasing with increasing population [5] but there is also a requirement to monitor health status of patient while he is in his personal environment. Advances have been made to provide real-time information feedback about wearer's condition, either to the user himself or to the supervising physician. Moreover, health monitoring systems are even implantable to deal with the postoperative rehabilitation patients and elderly people [6].

Molecular Structure of Silver Nanocrystals- Researchers from Xiamen University, China [7] has proposed the characterisation of two large, complex silver nanoclusters of 136 and 374 atoms. These diamond-shaped nanoclusters as shown in figure 2, provided by Australian Nuclear Science and Technology Organisation (ANSTO), consists of a silver core of 2 to 3 nanometres and a protecting layer of silver atoms and organic thiol molecules. X-ray diffraction and electron microscopy refined models for the crystal structures having five-fold core of 2-3 nanometres, the smaller core decahedral, while the larger elongated along the molecular 5-fold axis giving a series of convex polyhedral shells around a central silver atom.

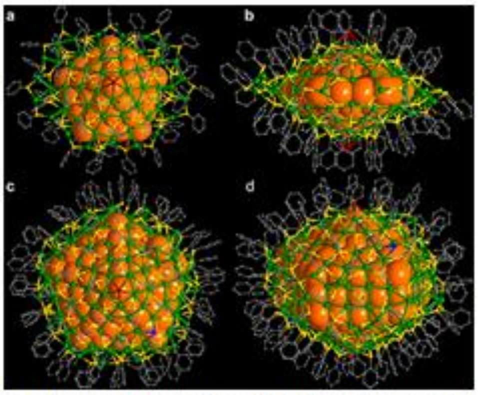

Fig 2. Overall structure of Ag136 and Ag374
Upper row: top and side view of Ag136 nanocluster
Lower row: top and side view of Ag374 nanocluster

Fourier Transform Infrared (FT-IR) spectroscopy was performed for the dried nano silver (60 °C)[8], in order to find out the presence of biomolecules that are responsible for stability and fluorescing molecules that are present on the surface of the nano silver. FTIR results predict the presence of aromatic residues as well as the disulphide bonds of proteins which contribute to the nano silver formation. A number of FTIR reports [9,10,11,12] suggests the presence of carbonyl groups in amino acid residue and peptides of proteins. These protein molecules form a protein coat on the nano silver surface which provides the stability to the nano silver in the aqueous medium [13].

According to Australian Centre for Neutron Scattering, the silver-136 compound has a core of 57 silver atoms in the shape of a pentagonal bi-pyramid surrounded by two 30 silver-atom dome-like structures which are then linked together. These 30-atom domes are also regular. The silver-374 compound core has 207 silver atoms in elongated pentagonal bi-pyramidal shells around a central silver atom. Instead of having tetrahedral that join together to make a decahedron, there are five wedge-shaped units which are like a tetrahedron that has been stretched out. The larger silver nanoparticle is also surrounded by two domed 30 silver atom caps. Polymers, metal ions, small organic molecules and biomolecules are known as capping agents and are used to control the shape of the nanocrystals. They are absorbed on a specific crystal plane and hence reduce the surface free energy. This induces the growth rate on a specific crystal plane. Since action mechanism is not completely known yet therefore trial and error attempts are made for the required shape [14].

Nano-scale Conductive Ink for Flexible Printing- Inkjet printing of functional materials is being studied at Binghamton University by Timothy Singler [15]. Functional materials are categorized on the basis of their functions they perform rather than on the basis of their origin. Solution-processed materials may have electrical, optical, chemical, magnetic, thermal or other functionalities. Silver is strongly

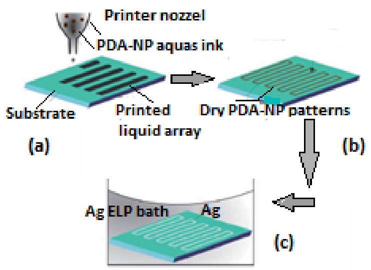

Fig 3. (a) Poly(dopamine) nanoparticles prepared as aquas ink and inkjet printed on glass and polymeric substrate (b) formation of pattern lines of PDA-NP after evaporation (c) Ag was site-selectively deposited on PDA-NP after electroless plating.

electrically conductive therefore can be formulated into nanoparticle ink for flexible substrates. Technique is developed which satisfies the various requirements of flexible printing such as low temperature, small size, good electrical conductivity and independent of substrate material etc. This involves inkjet printing of an aqueous suspension of synthesized mussel-inspired poly (dopamine) nanoparticles. Fine lines of printed nanoparticles deposited on both glass and polyethylene terephthalate (PET) substrates, shown in figure 3. These narrow lines of silver not only exhibited a resistivity 10.0 times that of bulk silver but also retained good electrical and adhesion performance even after many bending cycles.

Nano inks are currently a topic of research for low temperature bonding processes and printable electronics. Advances in the field of flexible printing have enabled us with a new ink that can be printed on textiles in a single step to form highly conductive and stretchable connections. In Japan researchers [16] have developed an elastic conducting ink that can be easily printed on textiles and patterned in a single printing step. This ink contains silver flakes, organic solvent, fluorine rubber and fluorine surfactant. The ink is highly conductive even when it is stretched thrice its original length. This is the highest value reported yet for stretchable conductors which is two and a half times their original length.

Wearable Technology in Monitoring Health Data- By the help of this new functional ink, electronic apparel such as sportswear and underwear can be manufactured that incorporate sensing devices for measuring a range of biological indicators. Biosensors can measure various physiological parameters e.g. blood pressure, heart rate, respiration rate, body temperature etc. and provide important information of body. The goal of wearable health technologies is to identify and track various physical activities of the wearer. Companies such as ‘Heddoko and Hexoskin’ have designed ‘smart shirts’ which use bio-sensing and moisture wicking fibers to keep the track of the bio mechanics and finally calculate calories burned based on the intensity of the workout and muscle stress. Another company ‘Mimo Baby Monitor’ presents a new application of this technology by keeping track on breathing and body position of infants.

Wearable technology has focused on health and fitness [17]. The technology includes a wide range of devices that enables us in collecting and displaying real-time health, motion and other important sensory data. However to accomplish this goal, there is a trade-off between accuracy and the power requirement for data analysis and storage. Data must be meaningful to the user in order to support their behaviours over a long period of time. If a large amount of raw data is being displayed to the user than this may lead to confusion and can discourage also. [18]. Currently wearable applications use a number of methods to avoid presenting huge raw data to the user and preventing cognitive overload from processing lots of information. Smart and context-aware algorithms are able to provide information about user from obtaining sensor data. Motivational suggestions can then be made at specific, influential times in the day. It is equally important that data should be under specific profiles. One of the major challenges is the amount of overall data to be processed during activity, since power required is directly dependent on it. Example is: data collected over ten-second increment takes twice as much as computing power as evaluating all the data over five second increment. The second challenge is the storage of that information. To reduce the power consumption, similar activity profiles given under one heading. A number of experiments have been performed and it was found that five relevant activities can be identified accurately using increments of six seconds. In other words not data related to different activities can be stored efficiently. However, this approach gives good results to track and record various physical activities and provide meaningful information to the users of wearable health monitoring devices.

CONCLUSION

However wearable availability has increased and wearable applications are more beneficial as compared to mobile apps, yet still further research is required to make them more adaptable for various settings. This may lead to long term retention of future of wearable devices. There is a proven novelty factor when it comes to health data as stated in [19], but long-term retention has to be ensured.

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