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Ultrafast Laser-Synthesized Gold–Silver Nanoalloys: Exploring Optical and Electrical Properties

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ABSTRACT: The aim of this study is to determine the optical and electrical properties of various Au-Ag nanoalloys. Gold and silver ions were directly irradiated in a quartz cuvette using a femtosecond laser, leading to the formation of nanoparticles in approximately ten minutes. We performed a thorough analysis of the optical characteristics of each sample, focusing specifically on the LSPR peaks. Researchers utilized dynamic light scattering (DLS) to measure the material's electrical conductivity and zeta potential. Thus, the method for assessing electrical conductivity was streamlined. The assertion is validated by the findings, which offer compelling evidence to support it. The peak localized surface plasmon resonance (LSPR) of gold was 530 nm, whereas that of silver was 409 nm. The effect was attained by integrating silver with a wavelength of 409 nanometers into the nanoalloys. Direct modifications to specific characteristics are easier to implement due to the linear nature of the alteration. Pure silver nanoparticles (Au0Ag100) exhibited enhanced electrical properties relative to pure gold nanoparticles (Au100Ag0). The conductivity values of the Au-Ag nanoalloys remained unchanged within this limited range.

Keywords: *optical properties, electrical properties, Au-Ag nanoalloys, photochemical reduction, femtosecond laser.*

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1. INTRODUCTION

The potential for nanotechnology to become ubiquitous is increasingly recognized. A lot of different fields value the progress made in creating new and better materials that could be used in optics, electronics, and catalysis. In many fields, many types of technological products are still in their early stages of development. New methods have had to be created because of the growing need for nanoparticles in chemistry, biology, and physics. Metal nanoparticles can form on the ground or on the surface, depending on the conditions. To start the top-down nanoparticle synthesis process, you need a completely clean space. No matter whether it is done mechanically, chemically, or physically, this treatment works. The scientific community defines a "nanoparticle" as a very small atomic or molecular thing made up of different elements. With this method, a composite material was successfully made. To follow the bottom-up approach, particle size needs to be closely watched and managed. It is possible to make these chemical parts dissolve in a number of different ways. Several methods are used in the process described, such as ultrasound, mechanical and electromagnetic oscillations, and reductive methods. Using femtosecond lasers and photochemical reduction together can make it easy to make materials quickly that contain nanoparticles. Because a dispersing agent and a metallic salt are used, this process is completely safe for the environment. Unfortunately, the organization has chosen to ignore the assets that were given to it voluntarily. The process of making nanoparticles depends on breaking down metal complexes into their basic parts. Because they can absorb light, gold and silver nanoparticles are the subject of a lot of research right now. These are the main things that determine the LSPR shift: the medium's size, shape, and dielectric constant. More research needs to be done to see if Au-Ag nanoalloys can copy the electrical, optical, and catalytic properties of the parts they are made of. When compared to single metal-based silver nanoparticles, titanium and silver nanoalloys work better. The main goal of this study is to look into the optical properties of Au-Ag nanoalloys that were made using femtosecond lasers and photochemical reduction. The amount of Au-Ag nanoalloys in a sample has a big effect on their optical properties, especially their LSPR (localized surface plasmon resonance) ability. Because of something called localized surface plasmon resonance, Au-Ag nanoalloys have a wide range of electrical properties, such as conductivity, voltage, and the amount of gold to silver nanoparticles they contain. Dynamic light scattering was used to find out the zeta potential and electrical conductivity of Au and Ag nanoalloys.

2. EXPERIMENT

Chemicals and instrumentation

Dynamic light scattering (DLS) proved to be an effective method for measuring the electrical conductivity and zeta potentials of these nanoalloys. With this technique, we can precisely alter the optical and electrical characteristics of Au-Ag nanoalloys, which in turn improves our understanding. Users of these substances are prone to innovative technological breakthroughs that will reshape our world. The production of nanoalloy particles made of silver and gold was previously only possible using extremely powerful femtosecond lasers. To reduce the concentrations of gold and silver, precise photochemical techniques were required. Radioactive decay produces numerous radicals, solvated electrons, and hydrogen atoms. To conduct this test, we combined 99% Rofa Lab silver nitrate with 99.95% Sigma-Aldrich potassium gold(III) chloride. Our solution contained both metals. Everything we had gathered was neatly put away. A mixture of the ingredients with dissolved gold and silver in water is used to make the coating. Every product made by Sigma-Aldrich uses polyvinyl chloride that is 99.99% pure. It is possible to determine the concentration of silver and gold ions in a solution using the methods laid out in Table 1. The AuxAgy model is defined by two variables, X and Y, which characterize the sample population. A three milliliter volume of liquid was contained in a glass cuvette and subjected to a laser beam for the purpose of the experiment.

Table 1. AuxAgy is a skill component.

Ratio	(Au:Ag)	Ratio	(Au:Ag)
Au_0Ag_{100}	0 mL : 3 mL	$Au_{60}Ag_{40}$	1.8 mL : 1.2 mL
$Au_{10}Ag_{90}$	0.3 mL : 2.7 mL	$Au_{70}Ag_{30}$	2.1 mL : 0.9 mL
$Au_{20}Ag_{80}$	0.6 mL: 2.4 mL	$Au_{80}Ag_{20}$	2.4 mL : 0.6 mL
$Au_{30}Ag_{70}$	0.9 mL : 2.1 mL	$Au_{90}Ag_{10}$	2.7 mL : 0.3 mL
$Au_{40}Ag_{60}$	1.2 mL: 1.8 mL	$Au_{100}Ag_0$	3 mL : 0 mL
$Au_{50}Ag_{50}$	1.5 mL : 1.5 mL		

The experiment's UV-V is spectrophotometry (MayaPro 2000; Ocean Optics) was employed to identify the LSPR peaks of every investigated particle. The zeta potential and conductive properties of the colloids were determined using the PSA Nano Plus 3, a particle size analyzer manufactured by Micromeritics USA. The crystal structure and shape of the material was examined using transmission electron microscopy (TEM) and X-ray diffraction.

Procedure reaction

A hundred milliliters of distilled water, one gram of silver nitrate, and one hundred milliliters of potassium gold chloride are combined to create the solution. The concentration that was attained is 4.22 x 10^-4 M. Once we finish with this process, we will devise a new strategy. For the role of preferred vendor, Sigma-Aldrich was ultimately selected as the top contender. This resolution was determined to be effective based on the decision. There were 4.22 x 10^4 particles in the solution. This is the result of an exhaustive search. A mixture of 0.01 liters of 25% ammonia (NH4OH) and silver nitrate can expedite the nanoparticle production process at Rofa Lab. The process could be even more effective if these parts were put together. Two distinct substances must be combined in order to accomplish this. A hundred milliliters of gold ions and gold that was 99.9 percent pure were required for the experiment. The company was acquired by Sigma-Aldrich. Even the gold's purity remained unchanged, according to the findings. More than 0.01% of the material was polyvinylpyrrolidone (PVP).

3. RESULT AND DISCUSSION

Femtosecond lasers' exceptional volume-changing capabilities enable the production of abundant Au-Ag nanoalloys. Because of this, it is also feasible to produce these nanoalloys simultaneously. In order to accelerate chemical reactions in molecules of volatile solvents, intense laser light that rapidly produces reactive species can be used. Currently, researchers are extracting metal ions from various solutions by employing a diverse array of reactive species. A variety of radicals, including free radicals, oxidized radicals, and hydrogen ions, exist in the external environment. How effective would other equations be in this case compared to, say, the short-term H equations? The laser produces M0 molecules, which effectively neutralize M+ cations in solution, because of its strong reduction abilities. The process of creating nanoparticles is known as synthesis. To create a homogeneous nanoalloy, two metal precursors are laser-heated to extremely high temperatures and then mixed. A different reduction potential is associated with each of the two metal precursors. In order to assemble systems containing metals, such as silver and gold, phase diagrams of these elements are required. In this study, nanoalloys are primarily examined. These materials possess numerous practical applications due to their exceptional optical properties.

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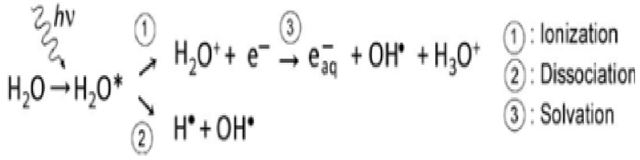

Figure 2 When water molecules absorb multiphotons using femtosecond laser energy, these are the initial reactions that occur.

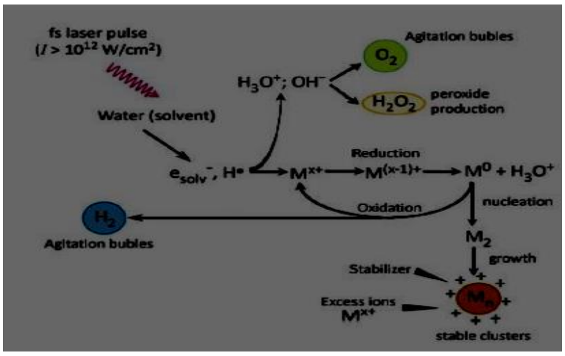

Figure 3. A schematic method is employed in conjunction with a powerful femtosecond laser to produce nanoparticles from water.

Figure 4. The LSPR peaks are proportional to the gold/silver ratio, according to the UV-Vis absorption spectra. The absorption spectra revealed the presence of gold and silver nanoparticles at 530 nm. The application of the wavelength dependency method could be to blame for this. One possible explanation is that this is due to the metallic properties of silver nanoparticles. Possible explanations for the nearly linear LSPR changes observed in these regions include changes in the chemical composition of the nanoalloy. Due to their malleability and abundance of chemical components, scientists have demonstrated that Au-Ag nanoalloys can undergo transformations.

Table 2. describes the electrical conductivity of Au-Ag nanoalloys and their zeta potential.

Sample	Zeta Potential (mV)	Conductivity (mS/cm)
Au0Ag100	-37.1	0.294
Au20Ag80	-23.5	0.291
Au50Ag50	-25.5	0.283
Au80Ag20	-26.5	0.265
Au100Ag0	-12.5	0.253

Three distinct nanoparticle materials are being investigated by the researchers employing X-ray diffraction (XRD). Consequently, three distinct nanoparticles are synthesized: one comprising purely gold, another of purely silver, and a third with an equal proportion of the two metals. Figure 5 shows lattice planes, which are used to determine the purity and alloy composition of nanoparticles. One hundred and twenty-two, three hundred and eleven, 111, and 222 planes are presently aerial. The final form of a face-centered cubic lattice crystal can be predicted with high degree of certainty. The homogeneous colloidal structure is what sets gold and silver nanoalloys apart from conventional metal alloys. Contrary to the first two alloys mentioned, this one is unique.

Figure 5. In order to learn about the crystal structure, lattice constant, and form of Au-Ag nanoalloys, XRD is used.

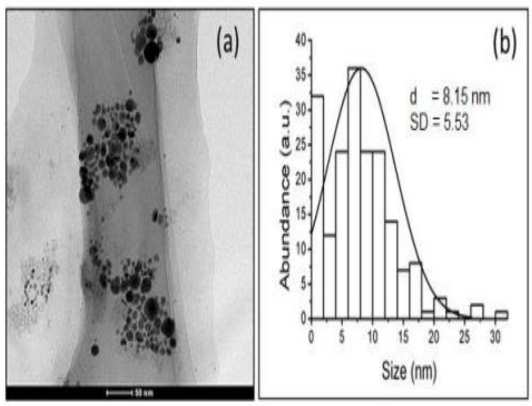

Figure 6 shows the 10-minute process of making the Au50Ag50 nanoalloy using femtosecond laser irradiation. The findings

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indicate that particles ranging in size from 5 to 30 nanometers can be produced by the Au50Ag50 nanoalloy. Reliable sources reported that the size of the nanoparticles ranged from 5.53 to 8.15 nanometers. As an example, transmission electron microscopy demonstrates that metals' intrinsic flexibility allows them to construct extremely stable structures. Combining metals can create structures with extremely long lifespans, according to research. In support of the theory, the alloy's UV-Vis spectra show a strong LSPR signal. Two distinct peaks can be observed in the correlation spectra. Distinct regions of the nanoparticle are revealed by these two peaks. One depicts the exterior, while the other shows the interior. Those paying close attention can still make out distinct peaks. The process of converting metal ions into metal atoms requires a five-minute warming period for the femtosecond laser. Ensure that the laser is functioning properly. The manufacturer of the lasers claims that after ten minutes of use, some of their efficacy is lost. The desired result is achieved when the microparticles are forced together by the thermal conduction of the laser. Particle size distribution might be affected by the degree of nanoparticle adhesion in the final step. The localized surface plasmon resonance (LSPR) technique is employed in Figure 4 to illustrate the distinction between the gold and silver nanoalloys. This distinguishes it from the rest. Nanoparticles made of pure metals, such as gold and silver, do not have this property. You can see the effect of band position on the conductivities of silver-gold nanoalloys in Table 1. Optimal silver-to-gold nanoparticle ratios can be achieved by tuning the electrical and optical characteristics of Au-Ag nanoalloys. This theory is further supported by additional evidence. Mixing two metals while they are hot and changing their ratios produces a microalloy. The AuxAgy variables, which display the volume ratios of gold and silver ions separately, are located on the x and y axes, respectively. Although Gaudry and colleagues discovered that the AuxAgy dielectric constant for silver increased with the volume ratio, the increase was only 19.4 cm rather than 38.5 cm. I found this to be an intriguing finding. An important finding was made here. How drastically different this was from gold's value was mind-boggling. The dielectric constants of the three materials can be changed by adjusting the volume of the gold and silver nanoalloys. Table 2 shows the correlation between electrical conductivity and localized surface plasmon resonance (LSPR) in nanoalloys made of silver and gold.

4. CONCLUSION

It would appear that different materials have different optimal uses. The new method of producing Au-Ag nanoalloys takes only around ten minutes and makes use of femtosecond lasers in conjunction with a rapid photochemical reduction process. The colloids were thoroughly examined using a variety of techniques, including X-ray diffraction, UV-visible spectroscopy, and dynamic light scattering (DLS). In this experiment, we see the advantages of Au-Ag nanoalloys as well as the individual metals' strengths. Results showed an LSPR of 409.06 to 530 nm and a conductivity of 0.253 to 0.294 mS/cm. The altered optical characteristics brought

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about by the nanoalloys are responsible for these findings.

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