Synthesis and characterization of high-purity gold nanoparticles by laser ablation method using low-energy Nd:YAG laser 1064 nm

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Abstract. High-purity gold nanoparticles (GNPs) has been successfully synthesized by using laser ablation method utilizing low-power neodymium yttrium aluminum garnet (Nd:YAG) laser at the fundamental wavelength. Experimentally, pulse laser beam (Nd:YAG laser, 1064 nm, 7 ns, 30 mJ) was directed and focused onto a high-purity gold sheet (99.95 %), which was placed into a pure liquid of deionized water, to produce GNPs colloid. Dark-red color colloid of high-purity GNP was successfully synthesized. The GNPs had a spherical shape with an average diameter of 23.5 nm and standard deviation of 6.4 nm. The surface plasma resonance was centered at wavelength maximum at 520 nm.

1. Introduction
Nanoparticles (NPs) have become scientific products, which are intensively being explored for various uses fields. NPs are microscopic particles with a dimension between 1 to 100 nm. One of the NPs intensively studied was gold nanoparticles (GNPs) [1-3]. GNPs have become a great interest for many scientists to be applied in various fields as catalysis [4], surface-enhanced Raman scattering [5], photonics device [6], electrochemical sensors [7], and medical applications [8]. In the medical field, GNPs were applied as drug carriers, contrast agents, thermal therapy, and radiosensitisers due to its peculiar characteristics compared to the bulk material including electronic, optic, and chemical properties [9,10].

Various methods have been employed to synthesize GNPs such as Turkevich, Brust, sol gel and chemical methods [11,12]. However, those methods required very delicate sample pretreatment, time-consuming, and labor intensive. Furthermore, ultrahigh-purity nanoparticles could not be produced due to the impurity coming from additional agents and stabilizers during their synthesis. The other method was physical technique such as pulse laser ablation (PLA), which involves high-power pulse laser as an energy source.

PLA method is very potential for synthesizing GNPs with high-purity, which is required for medical applications such as drug delivery, contrast agents and radiosensitizer [8]. Compared to other synthesis methods, PLA only uses very simple procedure and free from chemical agents and stabilizers, and therefore high-purity nanoparticles can be simply and rapidly produced. In this technique, the pulse laser was directed and focused onto a high-purity metal, which is placed into a pure liquid such as deionized water, to produce GNPs colloid. The colloid contained high-purity GNP ablated from the pure gold metal due to laser bombardment. In PLA, the femtosecond laser is
commonly used as an energy source for material ablation, which results in gold particle at various sizes. The other laser used in PLA is pulse nanosecond laser. However, the laser with high-power (more than 50 mJ) is usually employed to ablate the high-purity gold metal immersed in the pure water [10].

In this study, pulse Nd:YAG laser with low energy (around 30 mJ) was employed as an ablation source for GNPs production. The GNPs was then characterized morphologically by scanning electron microscopy (SEM). Size distributions and surface plasma resonances were also studied. Nanoparticle size of gold with low standard deviation was successfully produced. The present technique using low-energy Nd:YAG laser potentially suppress the production cost and effectively produces the GNPs with the low size distribution of nanoparticles.

2. Experimental procedure

Basic experimental setup used in this research is shown in Fig. 1(a). A high-purity gold metal sheet (99.95%) was placed at the bottom of a glass petri dish, which was filled with 7 ml pure aquades. A Nd:YAG laser beam (New Polaris II at the fundamental wavelength of 1064 nm, 50 mJ) was focused on the surface of the sheet by a convex lens to ablate the sheet to produce GNPs. The repetition rate and pulse width of the laser beam were 15 Hz and 7 ns, respectively. The laser beam was bombarded on the sample surface for the duration of 10 minutes consecutively. It should be pointed that during laser bombardment, the gold sheet and solution were periodically moved to achieve a homogeneous GNPs colloid and new-sheet position.

![Figure 1. (a) Experimental setup used in this study, (b) GNPs colloid](image)

The GNPs produced in this research was then characterized by using various techniques. Morphology study was made by Scanning Electron Microscopy – Energy Diffraction X-ray (SEM-EDX, JEOL JED-2300). Size distribution of nanoparticles was characterized by particle size analyzer (DelsaNano) and Surface plasma resonance was analyzed by using Ultraviolet-Visible (UV-Vis) light spectroscopy.

3. Results and discussion

Gold nanoparticles (GNPs) colloid produced in this study is shown in Fig. 1(b). Dark-red color GNPs was successfully synthesized by using the present technique of PLA utilizing low-energy Nd:YAG laser. The color of GNPs colloid is similar to the results obtained by other researchers published here [13]. It should be emphasized that the GNPs produced in this study have very high-purity because no additional agents and stabilizers used in the synthesis process.

Figure 2(a) shows the morphological characterization of GNPs obtained by using SEM-EDX. The magnification of obtained figure was set at 20000, resulting in smallest particle measurement of 1 μm. It can clearly be seen that the spherical shape of GNPs was produced with various size distribution. To
obtain this photograph, 1 mL GNPs colloid was poured on Si sheet and placed at a cleaned room with a temperature of around 30°C for 24 hours. To measure the particle size of GNPs, particle size analyzer was used. The average diameter of GNPs is 23.5 nm with a standard deviation of 6.4 nm as shown in Fig. 2(b). It should be mentioned when the laser energy was increased from 30 mJ (Fig. 2b) to 40 mJ, the diameter of GNPs also increased to 29.5 nm. This result has the same tendency with the result published by Piriyawonget. al. in nanoparticle alumina [14], namely the diameter of nanoparticle increased with increasing the laser energy.

![SEM-EDX image of GNPs](image1)

Figure 2.(a) Morphology of GNPs by SEM-EDX, (b) average diameter of nanoparticles measured by PSA method.

Figure 3 shows the absorption spectrum of GNPs obtained by using UV-Vis. The surface plasmon resonance (SPR) can clearly be seen at center wavelength of 520 nm. Single SPR certified that the gold nanoparticles were produced in the form of spherical shape.

![Absorption spectrum](image2)

Figure 3.Absorption spectrum of gold nanoparticles produced by using the present method

4. Conclusion
This study has demonstrated that pulse laser ablation method using low-power Nd:YAG laser can be employed to synthesize high-purity gold nanoparticles (GNPs) in aquades. The GNPs were characterized by using SEM-EDX, particle size analyzer (PSA), and UV-Vis spectroscopy to identify the morphology, size distribution, and surface plasmon resonance of GNPs, respectively. GNPs with the form of spherical shape and average diameter of 23.5 nm were produced. The results certified that low-power Nd:YAG laser can be successfully used to produce gold nanoparticles with high purity and
quiet homogenous in size distribution. Therefore, the use of low-power laser can potentially suppress the cost of GNPs production.

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