Femto-nanosecond laser ablation of gold target in liquid

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Abstract. Colloidal solutions of gold nanoparticles were generated in deionized water from bulk target at different energies of nanosecond and femtosecond lasers. The obtained colloidal nanoparticles were characterized by scanning electron microscopy, optical transmission spectroscopy and dynamic light scattering.

1. Introduction

Metal nanoparticles are used in different fields of science and technology due to unique optical, chemical, catalytic properties [1-2]. It is known that Au is catalyst, and used in a wide variety of catalytic reactions, such as oxidation, water reduction [3-4]. Addition gold nanoparticles have recently emerged as an attractive candidate for delivery of various payloads into their targets [5-6]. Gold nanoparticles have a lot of different applications, such as immunoassay [7], and detection of cancer cells [8], in electronics [9-10], therapeutics, sensors and diagnosis [11-12]. Addition they are widely used in biology (effect of the “nano-hype”) [13]. The generation of nanoparticles by method of laser ablation has advantages compared to conventional methods, like the purity and stability of the fabricated colloidal nanoparticles [14].

There are a large works devoted to laser generation of nanoparticles. But it is not studied a comparative role of laser parameters, such as wavelength, pulse widths, pulse energies in controlling the nanoparticle sizes, morphology and production rate [15]. For example some of works demonstrated the use of laser fluence, focusing conditions, different laser wavelength in controlling the size distribution of nanoparticles [16-17].

In this work colloidal gold nanoparticles were investigated depend on laser pulse duration, pulse energy, scanning velocity for two different experimental setups.

2. Materials and methods

Bulk gold used in this work was exposed to radiation of an HTF MARK fiber laser marker (Bulat) on Yb$^{3+}$ ions with a laser pulse FWHM of 120 ns, maximum pulse energy $E_{\text{max}} = 1 \text{ mJ}$, and pulse repetition rate $f \leq 80 \text{ kHz}$ and Yb-fiber femtosecond laser Satsuma (1030 nm, 0.3-10 ps, $E_{\text{max}}$ up to 10 µJ) (Fig.1).
Fig. 1 Experimental setups with (a) nanosecond laser, (b) femtosecond laser

The laser beam was focused by a galvanoscanner with an objective focal length ≈100 mm. Several ablation laser regimes with varying scanning speed and pulse energy were investigated. Pulse repetition rate was fixed and equal to 20 kHz. The target was arranged in a glass beaker with deionized water of a volume ≈2.5 ml (height above the target ≈ 1 cm). The laser beam was focused through the liquid layer onto the target surface. The minimum size of the focusing spot (1/e-diameter) $D_0 \approx 40 \mu m$ for nanosecond treatment and $D_0 \approx 20 \mu m$ for femtosecond. The size of the scanning area was 10 mm × 20 mm. Transmission spectra of the colloidal solutions were recorded on a UV-IR spectrometer (SF-2000, OKB Spektr) in the range of 200-1000 nm. Obtained nanoparticles were visualized by JEOL 7001F scanning electron microscope (SEM). For this colloidal gold nanoparticles were deposited onto a silicon wafer substrate. The chemical composition was confirmed by energy dispersive x-ray spectroscopic chemical microanalysis (EDX) using the INCA module (Oxford Instruments, England) of the electron microscope. The nanoparticle size distribution was analyzed in colloidal solutions by dynamic light scattering, using a Photocor Compact.

3. Results and discussions

Transmission spectra of the colloidal solutions of nanoparticles was studied in the range of 200-1000 nm. The main characteristic feature of the curves is the localized plasmon resonance of the gold nanoparticles at the wavelength of ~523 nm for nanosecond and ~530 nm for femtosecond treatment.

Dependences of the colloidal extinction coefficient at the plasmon resonance wavelength on the pulse energy for various laser durations are plotted in Fig.2 (a). The extinction coefficient increases versus the increasing energy. The extinction for a duration of 0.3 ps is lower than for 10 ps, which may be due to the occurrence of nonlinear effects in the liquid, such as filamentation [18]. Nanosecond laser ablation was accompanied by the presence of a plasma plume on the target surface [16, 19]. The dependences of the extinction coefficient on energy were plotted for different scanning speeds ($V=40-1500$ mm/s, $N=1-25$ pulses per point) (Fig.2d). The highest extinction is observed for the lowest velocity. Extinction decreases with increasing scanning speed (with a decrease in the number of pulses per point). With increasing energy, the extinction generally increases with the exception of the lowest and highest velocities. For the scanning speed of 40 mm/s, the decay of the extinction curve with increasing energy is associated with the production of a larger amount of nanoparticles, which subsequently screen laser radiation and impede the further generation of nanoparticles. The boiling of the liquid with increasing energy has an effect. Bubbles appearing above the target surface, also shield the laser radiation.
Fig. 2 Dependence of extinction coefficient on pulse energy for femtosecond laser generation (a), for nanosecond generation (d); SEM visualization of Au NPs deposited on silicon wafer (inset: EDX analysis) (b,e); Distribution of nanoparticles sizes for E = 4.5 μJ (c,f)

Scanning electron microscopy has shown that nanosecond and femtosecond laser ablation produce spherical nanoparticles. The particle size distribution showed that nanoparticles produced by femtosecond pulses are characterized by a broader size dispersion in the range from 10 to 300 nm with the maximum at about 100 nm. With regard to nanosecond generation, the average nanoparticle size varies from 5 to 175 nm with a maximum from 25 to 50 nm, depending on the scanning speed.

Conclusion

In this work, we investigated the effect of laser parameters, such as the duration of laser radiation, pulse energy, scanning speed (number laser pulses per point) for obtaining nanoparticles. The effect of the influence of the nonlinear effect of filamentation at 0.3 ps on the production of nanoparticles is observed. Phase explosion is a characteristic mechanism for the generation of nanoparticles during femtosecond laser ablation. The optimal modes for nanosecond and femtosecond generation of nanoparticles have been revealed. As a result of nanosecond generation, nanoparticles with smaller sizes are predominantly obtained.

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