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Development of double-pulse lasers ablation system for generating gold ion source under applying an electric field

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ABSTRACT

Double-pulse lasers ablation (DPLA) technique was developed to generate gold (Au) ion source and produce high current under applying an electric potential in an argon ambient gas environment. Two Q-switched Nd:YAG lasers operating at 1064 and 266 nm wavelengths are combined in an unconventional orthogonal (crossed-beam) double-pulse configuration with 45° angle to focus on a gold target along with a spectrometer for spectral analysis of gold plasma. The properties of gold plasma produced under double-pulse lasers excitation were studied. The velocity distribution function (VDF) of the emitted plasma was studied using a dedicated Faraday-cup ion probe (FCIP) under argon gas discharge. The experimental parameters were optimized to attain the best signal to noise (S/N) ratio. The results depicted that the VDF and current signals depend on the discharge applied voltage, laser intensity, laser wavelength and ambient argon gas pressure. A seven-fold increases in the current signal by increasing the discharge applied voltage and ion velocity under applying double-pulse lasers field. The plasma parameters (electron temperature and density) were also studied and their dependence on the delay (times between the excitation laser pulse and the opening of camera shutter) was investigated as well. This study could provide significant reference data for the optimization and design of DPLA systems engaged in laser induced plasma deposition thin films and facing components diagnostics.

1. Introduction

Double-pulse lasers ablation (DPLA) technique is high productive and reduce processing cost for many applications. DPLA is frequently used as a sample introduction technique for mass spectrometry (e.g. DPLA–ICP-MS), as well as being used to perform double-pulse lasers induced breakdown spectroscopy (DP-LIBS) [1–3]. The created plasma contain a rich source of ions with good beam quality which are needed in various applications such as radioactive ion beam production, high energy ion implanters, providing beams of hundreds of amperes for fusion applications, nano-amperes for microprobe trace analysis, nanostructures, lithography, space thrusters, pulsed laser deposition, laser material processing, military and accelerator applications [4–7]. The physical properties of the plasma in vacuum glow discharge still need various fundamental studies. The DPLA in the presence of an applied potential could provide high-density plasma which increases the discharge current due to trapping of the electrons and collision processes between the ions, electrons, atoms and neutral molecules. Progress in this field is largely paid by the facts that fundamental aspects of DPLA and consequent ion source generation are involved. The crossed-beam DPLA configuration is a superior ablation technique as compared with single-pulse laser ablation (SPLA) configuration to understand the generation and expansion dynamics of the ions source. The quality performance of the DPLA technique is strongly dependent on the selection of the experimental conditions. Recently, laser ablation (LA) of solid targets has been studied by installing lasers of different pulse durations in nanosecond regime [8]. In addition, application of low pressure of gas discharges are widely used in plasma spraying, plasma polymerization, charged particle accelerators, plasma processing, plasma display panels, fabrication of thin films by sputtering and etching, surface treatments and light sources [9–15]. Most of these applications required good understanding of laser-ablation and generation of ion sources. Ion flux, energy and velocity distribution are important to understand the mechanism of ions applications. The dynamics of ion sources released from copper, silver, stainless steel and titanium plasmas at different laser wavelengths have been studied [16–19]. A Faraday-cup ion probe is employed to collect and detect the released ions. The buffer gas used is commonly argon, because it is chemically inert

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and has two high lying metastable states. These two states ($1s_5(^3P_2)$ and $1s_3$ $(^3P_0)$) have a relatively long life-time [20], because the single photon transitions to the ground state are spin-forbidden.

Gold (Au) coatings sputtered onto polyethyleneterephthalate (PET) surfaces induced by laser irradiation, leads to form gold "nano-wires" at the ridges of the ripple structures [21]. Moening et al. [22] examined the field-emission properties of micro-pumps with gold thin films formed by a single laser pulse. Ruffino et al. [23] studied the effects of nanosecond laser irradiation on 5 nm thick Au film sputter-deposited on Si (111) for plasmonics devices applications. The growth of gold island films on the surface of dielectric substrates has been also investigated [24]. Gold is the top of the series indicating it's highly resistance to oxidation and corrosion. Gold does not form oxides or sulfides, so it has greater longevity. The electrical conductivity of gold is only $48.7\times10^6\,(\Omega^{-1}\,\mathrm{cm}^{-1})$. Therefore several electrical contact surfaces are plated with a thin coating of gold. The gold plating prevents the buildup of oxide layers that have a high resistance. Hence, it is employed for sensitive electronic devices, fusion reactors and plasma-facing components for this reason. The unique properties of gold at the nano-scale lead to its use in various applications such as colloids for biomedical marking, data storage, catalysts in organic synthesis and pollution control [25–27]. Gold has an ability to produce heat after absorbing light; therefore it can be used in a medical usage named as photo-thermal therapy [28,29].

The presence of localized surface plasmons (LSP) guides to a strong enhancement of the electric field around a gold nanoparticles (Au-NPs) when incident photons in the visible region interacts with a collective oscillation of electrons in the nanoparticle. The increasing of the electric field attracted the attention of researchers for high-sensitivity bio/chemical analysis using Surface Enhanced Raman Spectroscopy (SERS) [30]. LSP depends on the shape and size of NPs, the electric permittivity of their environment and degree of interactions between particles [31–34]. The production of gold ions presented here could open up additional new fields for applications such as quantum dots, a small magnetic domains, photonic crystal structures and nano-engineered surfaces for enhanced biosensors.

In this work we produced gold ion source by developing the DPLA technique for improving laser-plasma deposition thin film and obtaining good quality thin films. The influence of ambient argon gas pressure, electrode spacing, laser wavelength and laser intensity was studied. Gold ion source is industry growing as the price of gold is constantly rising. The results of the present work could be useful for understanding the ablation process and characteristics (plasma parameters) of Au plasma for diagnostic optoelectronics devices through DPLA technique. As far as we know, not much effort has been paid to produce Au ion source and high current signal using DPLA technique. This new kind of research is playing a crucial role for thin film deposition process, optical switching and laser assisted ion implantation technique.

2. Experimental procedures

2.1. Laser configuration and electrode material

The DPLA configuration setup was performed in partial vacuum argon gas pressure as elucidated in Fig. 1(a) and (b). Two nanosecond Neodymium Yttrium Aluminum Garnet (Nd:YAG) laser sources (Brilliant Eazy, Quantel Lasers I and II) having 5 ns pulse width and 10 Hz repetition rate were employed. Both laser beams were operated at 266 and 1064 nm wavelengths in DP-configuration with 25 and 500 mJ laser energies respectively to produce

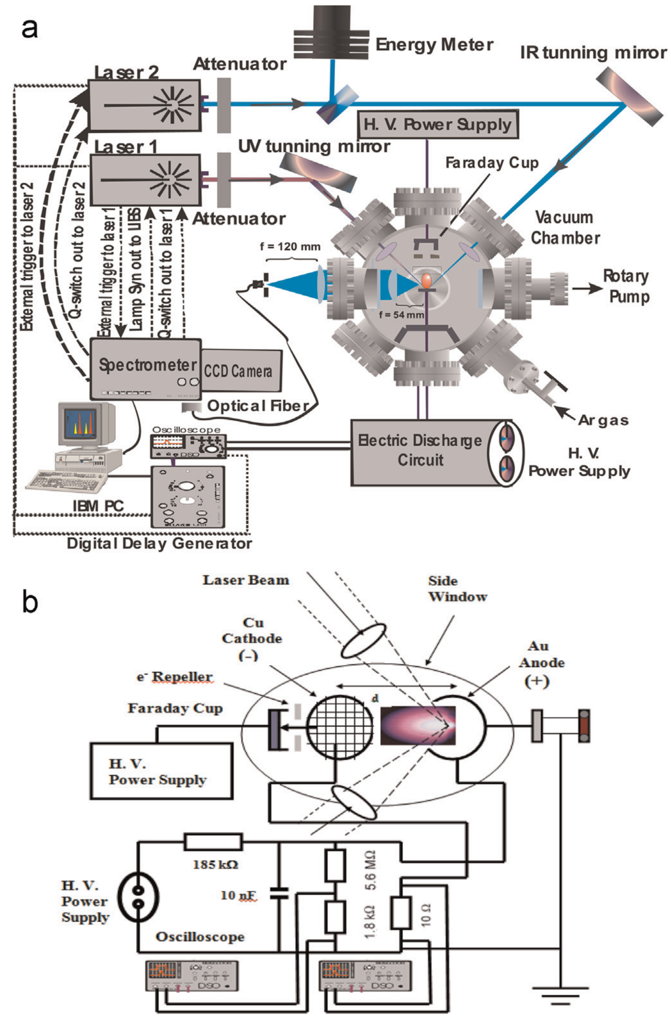

Fig. 1. (a) Schematic diagram of the experimental setup, (b) arrangements of laser focuses, collection optics, electric discharge circuit and a sample surface.

Au ion source. Many pairs of fundamental and harmonics of Nd: YAG lasers during the optimization process of DPLA technique were examined and assured that the combination (266+1064) nm revealed better S/N ratio. The energy of the laser beam was measured by means of a calibrated energy meter (Ophir Optics Model 300 Inc., USA). A quadrupled UV laser I with a digital transistor–transistor-logic output is installed to trigger the NIR laser II. With the help of certain turning mirrors and proper UV and NIR quartz lenses (f=20 cm), both laser beams were combined in an unconventional orthogonal (crossed-beam, DP-configuration) in opposite directions to focus onto a certain location on the gold electrode at a 45° angle of incidence. The flash lamps of both lasers were synchronized. The two laser spots are accurately aligned to focus on the same point on the Au target surface to produce the plasma plume in a vacuum-tight stainless steel chamber. The Au target was placed on a rotating stage to obtain a fresh surface after each laser pulse to prevent deep crater. The hybrid vacuum chamber for DPLA is fitted with quartz windows on its sides; therefore both laser beams passing through the windows can hit the planar anode (Au electrode) and deliver a photoelectric current. High purity gold (Au block 99.999%, Kurt J. Lesker) target of a circular shape was used as a planar anode. A copper (Cu) mesh grid; few mm thickness and circular shape, was employed as a planar cathode. Both planar-anode and planar-cathode are 50 mm in diameter and surface area of 706 mm². The anode/cathode distance was varied between 1.0 and 3.5 cm by using a movable