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Application of intense laser interaction with plasma in nanotechnology

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Laser plasma interaction is being used in almost every aspect of life be it medicine, environment, health, waste management or agriculture. Plasma generation via laser in nanoparticles has potential applications in various fields as diverse as medicine and materials processing. To fully harness this technique, it is essential to understand how nanoparticles behave in intense laser fields and how they can be controlled. In this article a review for the application of laser plasma interaction processes contributing towards nanotechnology has been introduced.

I. INTRODUCTION

As described by L. Filliponi and D. Sutherland, The Royal Society and the Royal Academy of Engineering [1, 2], nanoscience is the study of phenomenon and manipulation of materials at atomic molecular and macromolecular scales, where properties differ significantly from those at large scale. Nanoscale ranges roughly between 1 and 100 nm and materials may exhibit entirely different properties at nanoscale. For example at nanoscale materials may exhibit better conductivity of heat and electricity, enhanced tensile strength, change in magnetic properties and color change with change in size. Lee et al [4] have made conductive adhesive by adding nano-sized Silver (Ag) collides to the polyvinyl acetate (PVAc) emulsion. It ahs been shown that the addition of nano-sized silver collides helps in establishing the conductive path eventually lowering the resistivity. Fan et al [5] have shown the effect of nano-sized particles on electrical and thermal conductivity of electrically conductive adhesive (ECAs). Pervoskite $LaFeO_3$ shows antiferromagnetic behavior in room temperature [6], but nano- $LaFeO_3$ exhibits weak ferromagnetism in room temperature [7]. Jo et al [8] have shown that crystalline Ag nanoparticles having 4 nm diameter exhibit ferromagnetic behavior contrary to diamagnetic behavior in the bulk sample of Ag. Studies on magnetic nanoparticles are focusing on nanoparticles based on the synthesis of ferromagnetic metals like Co, Ni and Fe [9] due to interest in the fabrication of magnetic nanoparticles for application in ultrahigh density magnetic sensors and storage devices. Pal et al [10] studied the effect of nano-TiO_2 particles on the electrode characteristics and weld-metal tensile strength. It has been shown that the presence of nano-TiO_2 particles in the shield-metal-arc-wielding electrode coating improved the recovery of elements like Mn, Ni, Mo etc. and increased tensile of all-weld metal. The main reason for the drastic change in the physical and chemical properties of the nanoparticle as compared to their bulk materials may be attributed to the small size which enhances the exposed surface area and hence surface area to volume ratio [11].

Expeditious development in the ultra-intense laser technology has helped in reaching the maximum possible electromagnetic energy density as controlled sources currently available in the laboratories. Rapid growth in the available intensity in the laser has initiated study of nonlinear behavior in a number of basic systems like atoms, molecules and plasmas-resulting from the ionization of gases and solids [12]. The development of short pulse high intensity lasers has proved to be highly motivational for studying laser produced plasmas and its interaction with lasers [13]. Significant applications of laser plasma interaction include generation of highly energetic particles [14, 15] and Mev hard X-rays [16]. Tabak et al [17] proposed the use of highly energetic electrons for initiating inertial confinement fusion reaction. Other important applications of the interaction of intense laser radiation with plasma include laser plasma accelerators [18], second harmonic generation [19, 20], super continuum generation [21] etc.

Now a days the laser plasma interaction is being used in almost every aspect of life be it medicine, environment, health, waste management or agriculture. *P*lasma generation via laser in nanoparticles has potential applications in various fields as diverse as medicine and materials processing. To fully harness this technique, it is essential to understand how nanoparticles behave in intense laser fields and how they can be controlled. In this article a review for the application of laser plasma interaction processes contributing towards nanotechnology has been introduced.

II. NANOPARTICLE DETECTION AND CHARACTERIZATION

Laser plasma based techniques such as laser induced break down spectroscopy (LIBS) has been successfully applied for the analysis of nanoparticles [22]. This analysis may prove to be highly significant in effluent waste monitoring in atmosphere or in environment [23]. The technique is perfectly suitable for remote; in-situ and real time analysis of nanoparticles, minimizing sample handling or in the cases where the direct sampling is not possible (like radio active elements). This method is almost non-destructive as only a small fraction of the whole amount is used for elemental characterization. Laser induced break down detection technique (LIBD) is very sensitive method in which a tightly focused pulsed laser beam is incident on particles and the induced breakdown is detected either by using an acoustic or optical method. Barreda et al [23] used LIBD technique for the characterization of Tryptophan ($C_{11}H_{12}N_2O_2$) nanoparticle beams generated with an aerodynamic lens system (ALS). It has been demonstrated that the LIBD technique may detect nanoparticles of sizes as low as 5 nm. A number of studies of the interaction of intense laser fields with nanomaterials have been performed on nanoparticles in solution or on a surface which are often subject to surface or solvent effects. These studies typically probe many nanoparticles and provide average behavior of many nanoparticles. Variations in the size, shape, composition, surface structure and orientation of the nanoparticles are hidden, but these variations can have a substantial impact on their response to light [24].

Introduction of a gain material into metal nanoparticles can lead to surface plasmon amplification of stimulated emission of radiation (SPACER) [25]. Li et al [26] have shown that active metal nanosystems enhance local electric field intensity to a high level where single-molecule detection by surface enhanced Raman scattering can be readily achieved. A systematic analysis on the local field enhancement characteristic of cubic gold nanobox was made, that contains gain material within the core. Numerical simulations have shown that the composite metal nanoparticle can generate an extremely high enhancement factor of local field intensity exceeding 10^8 and a G factor on the order of 10^{16}-10^{17}. The laser optoacoustic method can be applied to detect and localize Gold nanorods at a very low concentration within the tissue where diffuse optical tomography fails to detect their targets. The high sensitivity of the optoacoustic method is because of the high contrast between light absorption of normal tissues and Gold nanorods in the near infrared region [27].

III. NANOPARTICLE SYNTHESIS

Nanoparticle can be produced by many techniques such as arc discharge [28], vapor deposition [29], electrochemical deposition [30] and ball milling [31]. Pulsed laser ablative deposition (PLD) has gained much interest for the production of thin films as well as NP's and their aggregates in the recent years. Eliezer et al [32] described theoretically the interaction of solid targets with femtosecond laser pulses predicting the optimal target and laser parameters for nanoparticles synthesis. Based on theoretical analysis experimental evidences have been shown for successful synthesis of aluminium nanoparticles. Synthesis of nanoparticles using femtosecond lasers has several advantages. First the femtosecond pulse does not interact with ejected material due to small pulse duration allowing the study of the thermodynamics and hydrodynamics of the plasma expansion and of the nanoparticle formation without any external disturbances. Second, the initial thermodynamic conditions are easily known because the density of the material remains unchanged via heating through femto second laser pulses. Third, for a femtosecond laser, the material is heated to a higher temperature and higher pressure because the laser is absorbed before any substantial thermal conduction and plasma expansion take place. The femto-second laser can heat a material to a solid like density plasma state with above-critical point temperature and pressure. Strum et al [33] have shown experiments on nano thickness films of Ag and Fe deposited under Ar pressure ranging from vacuum to 10 mbar, since collisions with the inert gas atoms are expected to change the energy distribution of the ablated ions. The radiation source used was excimer KrF laser with a pulse width of 30 ns. Ulmann et al [34] generated aerosols nanoparticles (approximately spherical), diameter ranging from 4.9nm to 13nm, by excimer laser ablation of solid surfaces. As a result of a reactive laser ablation process, Aerosols of oxides of titanium, aluminum, iron, niobium, silicon and tungsten were generated in an oxygen carrier gas. Gold and carbon aerosols were generated in nitrogen by non-reactive laser ablation. The aerosols were produced in the form of aggregates of primary particles in the nanometer size range. The pulse duration of the laser was about 28 ns. Pronko et al [35] examined plasma responses as a function of absorbed incident laser energy and compared them with the case of double pulses in which one pulse is time delayed with respect to the other. In the double pulse experiment each pulse had equal energy and each pulse had been so designed that the sum of the energies of the two pulses is equal to the sum of a single large pulse. It has been observed that a time delayed second pulse can be helpful in enriching the isotopes in an ultrafast laser ablation plume and create a controlled burst of uniform nanosized clusters with in the expanding plasma. By using pulsed laser ablation technique nanoparticles of graphite can be produced in an atmosphere of N_2 and in an air ambient at atmospheric pressure [36]. Significant interaction between laser pulses and nanoparticles was observed above a laser repetition rate of ~ 15 Hz. As a result of this interaction a decrease of the laser intensity on the target due to screening (absorption and scattering) and a decrease in the size of the formed nanoparticles due to laser heating followed by evaporation has been observed. For the small-sized particles (less than ~ 20 nm in diameter), laser-induced evaporation could be observed at lower repetition rates and could be explained by the larger angular distribution of the ejected material.

IV. SUMMARY AND CONCLUSION

When the femtosecond radiation acts on a solid target, the radiation energy is absorbed by the target itself after, several picoseconds the laser pulse the radiation-related ablation of material takes place, yielding to the ejection of atoms and small clusters. The nano-clusters coalesce during their subsequent cooling in the ambient medium, forming particles in the nanometer range. Laser induced breakdown spectroscopy (LIBS) is highly useful in determining the mass concentration and chemical identification of nano particles. Laser-plasma based technique play a significant role in understanding plasma-nanoparticle interaction and detection of carbon nanotube signature. In plasma explosion imaging localized plasma within isolated nanoparticle is created and the momentum of ejected ions is used to infer the location of this plasma. Hence in nutshell it may be concluded that laser plasma based techniques are proving to be an important tool for diagnosis as well as creation of nanoparticles.

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