JOURNAL OF INTENSE PULSED LASERS AND APPLICATIONS IN ADVANCED PHYSICS Vol. 3, No. 4, p. 47 - 50

Fundamental approach to clinical applications of intense pulsed light

K. RAVINDRANADH, M. C. RAO*
Department of Physics, Andhra Loyola College, Vijayawada - 520 008, INDIA

Nonlinear interaction of high energy laser beam with the matter has been an exciting area of research as it unravels both scientifically and technologically important phenomena which could be exploited in the design and fabrication of useful optical devices. As the nonlinear interaction of laser changes the surface morphology, structure, refractive index, formation of periodic gratings; it is possible to modify and control the optical and the electrical properties of the surfaces of the bulk samples and thin films. Lasers are devices that produce intense beams of light which are monochromatic, coherent and highly collimated. The wavelength of laser light is extremely pure when compared to other sources of light and all of the photons that make up the laser beam have a fixed phase relationship with respect to one another. The Laser used correctly in the medical practice offers clear advantages compared with traditional therapies. The improvement and even the elimination of many significant skin lesions can be achieved with reduced risks to patients. However, it is important to keep security measures and understand the possible effects on an experimental model. The intense pulsed light is used in a similar way to the excimer laser in the treatment of various pathologies of the skin: psoriasis, vitiligo, etc. Clinically it is also used to stimulate the regeneration of the cartilage in degenerative processes. It has been postulated that its action is based on the activation of the cell division, collagenous and elastic fibers formation, regeneration of blood vessels, cicatrisation of bone tissue and reepithelization of damaged tissue. This paper deals with the detailed study of intense pulsed light properties and their applications.

(Received October 7, 2013; Accepted November 15, 2013)

Keywords: Laser, Intense pulsed light, Plasma process, Pulsing and Applications

1. Introduction

Nonlinear interaction of high energy laser beam with the matter has been an exciting area of research as it unravels both scientifically and technologically important phenomena which could be exploited in the design and fabrication of useful optical devices. The possible effects as a result of high energy laser matter interaction could be the selective melting of the surface, ultra fast quenching, periodic energy deposition due to the interference of laser pulses, fast recrystallization etc. Accordingly, it would result in nanocrystallization, amorphous or glass formation, ridge formation and periodic structures depending on the nature of the materials and the interacting laser's wavelength, pulse width, peak intensity and duration of irradiation [1, 2].

A short light pulse produced in a laser oscillator is stretched temporally using a system of gratings before being introduced into the gain medium. As a result of the increase in pulse length, the intensity of the pulse remains below the damage threshold of the gain medium, the original limiting factor in maximum output intensity. After amplification, the laser pulse is passed through another series of gratings, reversing the dispersive stretching, reducing the pulse duration to one similar to the input pulse length. This technique allows the production of high power laser pulses in the petawatt regime, and is now being used to explore fascinating new physics with irradiances > 10^{21} W cm^{-2}. Such lasers can potentially heat material to relativistic energies and produce large volume approximately uniform plasmas. Similarly, other laser advances have enabled the development of cheap table-top lasers capable of producing interesting plasmas. The use of a table-top laser with focussed irradiances up to 10^{15} W cm^{-2} is described in this thesis alongside results from more intense lasers. High power lasers have been used to produce and probe the opacity of dense plasmas. There are difficulties in modelling the atomic and other physics involved in plasma opacity calculations, especially in the low temperature, high density regime [3].

Laser is a powerful source of light having extraordinary properties which are not found in the normal light sources like tungsten lamps, mercury lamps, etc. The unique property of laser is that its light waves travel very long distances with very little divergence. In case of a conventional source of light, the light is emitted in a jumble of e separate waves that cancel each other at random and hence can travel very short distances only. An analogy can be made with a situation where a large number of pebbles are thrown it into a pool at the same time. The interaction of laser beam with the solid matter is of great interest with the advent of high power lasers. The application of the Extreme Light Infrastructure (ELI) will open the way towards a new advanced physics in the field of interaction between the intense light and the matter in its condensed state. The methods Laser Induced Plasma Spectroscopy (LIPS) or Laser Induced Breakdown Spectroscopy (LIBS) are largely used in order to characterize the plasma formation, the laser beams and the targets [4].

One of the most controversial light-based technologies, which had its birthplace in San Diego in 1992 and was cleared by the US Food and Drug Administration (FDA) in late 1995 as the Photoderm, is noncoherent polychromatic filtered flash lamp intense pulsed light (IPL) source. It was initially launched and promoted as a radical improvement over existing methods for elimination of leg telangiectasia owing to pressure from venture capital groups that funded its development. The working premise for IPL is that noncoherent, polychromatic light can be manipulated with filters to meet the requirements for selective photothermolysis - that for a broad range of wavelengths, the absorption coefficient of blood in the vessel was higher than that of the surrounding bloodless dermis. When filtered, the Lumenis IPL device is capable of emitting a broad bandwidth of light from 515 nm to approximately 1,200 nm. This bandwidth is modified by application of filters that exclude the lower wavelengths [5]. IPL light describes the use of intense pulses of non-coherent light distributed over a range of wavelengths from 500 nm to 1200 nm, for removal of hair and other purposes. A related but distinct technique is laser hair removal; the primary difference is that laser treatment uses laser-generated coherent and monochromatic light.

2. Interaction of strong laser pulses with matter

The starting point of any laser-plasma interaction is the transition of the target material into plasma state due to the presence of the laser electric field. Experimentally, laser-induced ionization was observed shortly after the invention of the laser in the sixties already. With advances in laser technology, however, higher intensities, different wavelengths and shorter pulse durations became available. Depending on the laser parameters used, different ionization processes such as Multi-photon ionization, Above-threshold ionization and Barrier suppression ionization were discovered. The role of “nonlinear radiation forces” was investigated, what lead to what is today called ponderomotive force of a laser pulse [6]. Numerous theoretical models have been developed with the aim to quantify the ionization rates and to predict the kinetic energy of the electrons. And of course, during more than 40 years since the invention of the laser, a multitude of publications exist which cover experimental and theoretical aspects of laser-induced ionization and the role of the ponderomotive potential of a laser pulse. Even today there are many challenges and open questions left. For example, the quantum mechanical simulation of the ionization process induced by a picoseconds laser pulse in which an electron is accelerated to energies up to several times of the photon energy is extremely difficult despite of today’s computational power [7].

3. Laser-induced plasma processes

Two decades of intensive experimental research, enabled by the wide availability of terawatt (TW)-class fs lasers starting in the early 1990s, has yielded a generation of self-injecting laser-plasma accelerators (LPAs) of only centimeter length that have produced nearly mono energetic electron bunches with energy as high as 1 GeV [8, 9]. Scaling these compact accelerators to multi-GeV energy would open the prospect of building x-ray free-electron lasers and linear colliders hundreds of times smaller than conventional facilities, but until recently the 1 GeV barrier proved insurmountable. Fig.1 shows the schematic representation of laser-plasma accelerators.

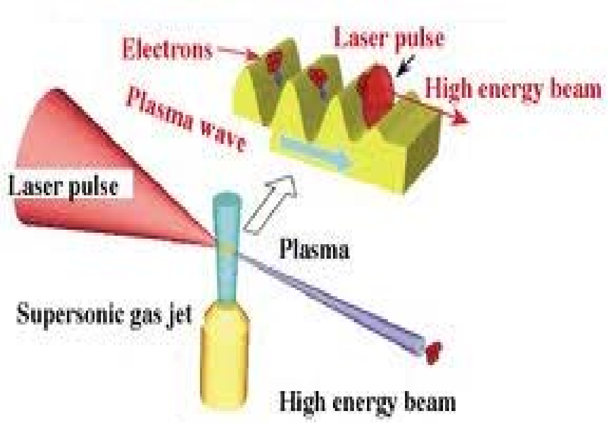

Fig.1 Schematic representation of laser-plasma accelerators

Once plasma is produced by the leading edge of an ultra-short laser pulse due to one of the ionization processes described above, the fundamental parameters relevant for the description of the plasma phenomena are essentially the electron density and temperature. A key question of interest is hence what is the energy transfer from the laser pulse into the plasma. This energy which is stored in kinetic motion of the electrons and which - after thermalization via collisions defines an initial temperature, forms the energy reservoir to drive other processes like collisional ionization and hydrodynamic expansion of the plasma created.

4. Spatio-temporal visualization of laser-driven plasma structures

Details of evolving laser-driven plasma structures are traditionally known only through intensive computer simulations based on estimated initial conditions. Frequency-domain holography (FDH), a technique in which the object modulates a co-propagating probe pulse has yielded detailed snapshots of linear and nonlinear plasma wakes, but averages over their evolution as they propagate. Transverse shadowgraphy has yielded multi-shot movies of evolving wakes, but averages over transverse structure and shot-to-shot fluctuations [10-12]. Recently Frequency-Domain Tomography (FDT) has shown promise for producing movie-like images of evolving laser produced objects in a single shot. In FDT, several probe-reference pulse pairs cross the object's path simultaneously at different angles. The evolving object imprints a phase streak onto each probe, from which a single-shot, multiframe movie is produced using tomographic reconstruction algorithms. Fig.2 shows the laser-driven plasma structure [13].

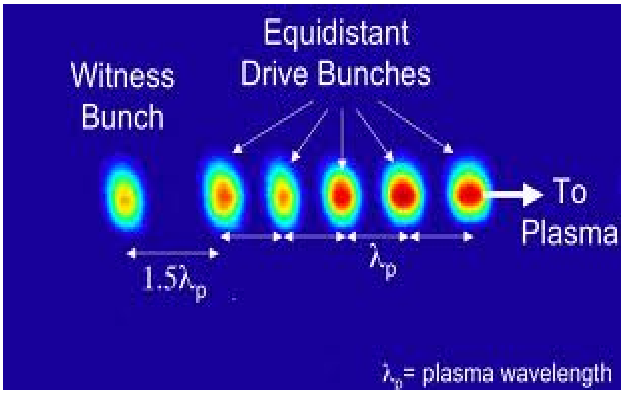

Fig.2 Laser-driven plasma structure

5. Concepts of Multiple Pulsing

The newest concepts for IPL and what has most contributed to the success of the technique are the ability to elongate pulse durations for larger vessels, shorten pulse durations for smaller vessels and use these in a variety of combinations of synchronized short and long pulse width [14]. For a small vessel (0.3 mm), heat distribution is assumed to occur instantaneously [15]. For a larger vessel, this cannot be assumed because more time is required to have heat pass from just inside the superficial vessel wall through the vessel to the deeper wall. Additional cooling time is required to release the accumulated heat from the core to the vessel surface. These principles were demonstrated using double-pulse experiments with the 585 nm yellow dye laser in which larger vessels of port-wine stains (greater than 0.1 mm) absorbed greater energy fluencies before reaching purpura after double pulses spaced 3 to 10 milliseconds apart [16]. In another study using pulsed laser irradiation at 585 nm, pulse durations were chosen between short pulse (0.45 ms) and long pulse (10 ms) [17]. The results demonstrated that long-duration pulses caused coagulation of the larger-diameter vessels, whereas small-caliber vessels and capillaries showed resistance to photothermolysis at these parameters. This concept has been termed photo kinetic selectivity. Applying this concept to IPL, It is observed that increasing pulse durations up to 12 ms causes larger vessels (0.5 mm or greater) to undergo more effective clinical photo thermal coagulation while sparing the epidermis [18]. Obeying the principles of thermo kinetic selectivity using IPL, the smaller overlying vessels in the papillary dermis do not absorb efficiently at longer pulse durations, causing less epidermal heating.

6. Applications of IPL

IPL technology is employed in the treatment of medical disorders of the skin including, sun damage induced dyspigmentation and vascular changes, Poikiloderma of Civatte, acne rosacea, vascular lesions and pigmented lesions. IPL treatment improves the appearance of photoaged skin, removes age spots, most benign brown pigments and redness caused by broken capillaries through a process called photo rejuvenation for face and body. The process is ideal for patients with active lifestyles because the procedure requires no downtime and has a low risk of side effects. IPLs use flash lamps, computer-controlled power supplies and band pass filters to generate light pulses of prescribed duration, intensity and spectral distribution. The light energy is converted to heat energy to treat skin conditions such as age spots, sun-damaged skin, cutaneous lesions, benign pigmented epidermal lesions and vascular lesions

Poikiloderma of Civatte: This photoaging process consists of an erythematous, pigmented and fine wrinkled appearance that occurs in sun-exposed areas, mostly on the neck, forehead and upper chest. For areas of poikiloderma on the neck and lower cheeks consisting of pigmentation and capillary matting, the IPL device is ideal with the use of a 515 nm filter, which allows absorption both by melanin and hemoglobin simultaneously. For patients with more dyspigmentation, one begins with higher filters, such as the 550 or 560 nm filter, to prevent too much epidermal absorption, which would result in crusting and swelling, lasting for several days. Additional treatments with the IPL may be performed with a 550, 560 or 570 nm filter to treat the vascular component of poikiloderma [19].

Facial Telangiectasia: The treatment of facial telangiectasia is the foundation of treatment of photoaging by IPL. The clinical observation was made following treatment of facial langiectasia that skin texture became smoother. The parameters for IPL of facial telangiectasia with the Lumenis Vasculite and Quantum IPLs include a double pulse of approximately 2.4 to 4 ms duration with a 550 nm filter in light skin and 570 nm filters in darker-skinned patients. Typical delay times are 10 ms in light skin and 20 to 40 ms in dark and Asian skin. The fluences required are typically between 28 and 35 J/cm^2. Higher fluences are used when the second pulse duration is greater than 4.0 ms.

7. Conclusions

The unique property of laser is that its light waves travel very long distances with very little divergence. IPL was initially launched and promoted as a radical improvement over existing methods for elimination of leg telangiectasia owing to pressure from venture capital groups that funded its development. The newest concepts for IPL and what has most contributed to the success of the technique are the ability to elongate pulse durations for larger vessels, shorten pulse durations for smaller vessels and use these in a variety of combinations of synchronized short and long pulse widths. IPL technology is employed in the treatment of medical disorders of the skin including, sun damage induced dyspigmentation and vascular changes, Poikiloderma of Civatte, acne rosacea, broken capillaries, vascular lesions and pigmented lesions. The process is ideal for patients with active lifestyles because the procedure requires no downtime and has a low risk of side effects.

Acknowledgements

The Corresponding author (M. C. Rao) is thankful to UGC for providing the financial assistance through Major Research Project (Link No. F. No. 40-24/2011(SR))

References

[1] V.I. Emel’yanov, Laser Phys. **2**, 389 (1992).
[2] Jeff F.Young, J.S.Preston. H.M.van Driel, J. E.Sipe, Phy. Rev. B **27(2),** 1155, (1983).
[3] F. Serduke, E. Minguez, S. Davidson, C. Iglesias, J. Quant. Spec. Rad. Trans. **65**, 527 (2000).
[4] C. Florea, M. Zamfirescu, F. Jipa, A. Velea, J. Int. Pul. Laser Appl. Adv. Phy. **1(1)**, 1 (2011).
[5] M. P. Goldman, R. A. Weiss, M. A. Weiss, Dermatol. Surg. **31**, 1179 (2005).
[6] B. W. Boreham, H. Hora, Phys. Rev. Lett. **42**, 776 (1979).
[7] K. Burnett, V. C. Reed, P. L. Knight, J. Phys. B **26**, 561 (1993).
[8] E. Esarey, C. B. Schroeder, W. P. Leemans, Rev. Mod. Phys. **81**, 1229 (2009).
[9] W. P. Leemans, Nature Phys. **2**, 696 (2006).
[10] N. H. Matlis, Nature Phys. **2**, 749 (2006)
[11] P. Dong, Phys. Rev. Lett. **104**, 134801 (2010).
[12] A. Buck, Nature Phys. **7**, 543 (2011).
[13] Z. Li, Opt. Lett. **35**, 4087 (2010).
[14] M. Keijzer, S. L. Jacques, S. A. Prahl, A. J. Welch, Lasers Surg. Med. **9**, 148 (1989).
[15] R. M. Adrian, Dermatol. Surg. **24**, 19 (1998).
[16] C. C. Dierickx, J. M. Casparian, V. Venugopalan, J. Invest. Dermatol. **105**, 709 (1995).
[17] S. Kimel, L. O. Svaasand, M. H. Wilson, J. Invest. Dermatol. **103**, 693 (1994).
[18] R. A. Weiss, M. A. Weiss, S. Marwaha, A. C. Harrington, Lasers Surg. Med. **24**, 128 (1999).
[19] R. A. Weiss, M. P. Goldman, M. A. Weiss, Dermatol. Surg. **26**, 823 (2000).

---

*Corresponding author: raomc72@gmail.com