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Effect of ultra-high acceleration of plasma blocks by nonlinear laser interaction: contributions at the University of Western Sydney

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***Editor's note**: The Royal Society of New South Wales has an active programme to engage high school and university students and to encourage a greater interest in science in young people. This paper describes a successful programme at both the University of Western Sydney and the University of New South Wales that made a valuable contribution in the "big science" arena.*

Abstract

An example is given, how a team in a growing university contributed to "big science", particularly towards a future option for a clean, unlimited and very low-cost energy source using lasers. The source is the nuclear fusion reaction in which hydrogen is converted into helium. The work described here contributes to the development of a route to nuclear fusion using ultra-high power lasers.

Keywords: Laser-plasma interaction; fusion energy by lasers; ultra-high acceleration of plasma

Introduction

A fundamental new phenomenon, the ultra-high acceleration of plasma at laser interaction, was measured by Sauerbrey (1996). This could be a key development in sourcing energy from nuclear fusion. Directly visible Doppler-effect measurements confirmed accelerations above 10^{20} cm/s^2 in agreement with numerical predictions based on the nonlinear theory for the interaction process (see figures 10.18a & b in Hora, 1981). This electromagnetic acceleration is more than 10,000 times greater than accelerations based on thermal processes due to gas-dynamic pressures was demonstrated and measured in 2011 with very large lasers with longer pulses (Park et al. (2010), Karassik et al. (2010)). The clarification and understanding of this phenomenon required several years of research. A team at the University of Western Sydney was involved and their contributions were summarised in the proceedings of a special conference held at the University of Western Sydney in cooperation with the University of New South Wales (Osman (2005), Hora et al. (2007)).

A crucial publication regarding these developments was documented in Hora et al. (2002) and is referred to extensively below. The crucial distinguishing characteristic of this phenomenon is the duration of the laser pulses. The thermally-determined acceleration from very intense laser pulses is in the nanosecond (ns) range, while the nonlinear electrodynamic interaction occurs with picoseconds (ps) pulses. The understanding of these phenomena emerged during the last 50 years with the study of intense laser pulse interaction, beginning with the discovery by Linlor (1963) of the energy of emitted ions. If the laser pulses had power, P, of less than the threshold P* of about a megawatt (MW), the interactions with targets were as predicted by classical theory. In this case, the targets were heated up to temperatures of 20,000 to 50,000 degrees, emitting ions with an energy of few electronvolt (eV) in a way that is well understood. When Linlor (1963) first used the then new "giant" laser pulses with about ten times higher power, unexpectedly, a large number of ions with thousands of times higher energy were measured. It was clear that these keV ions were not of thermal origin because they were in groups of ions with linear energy increase on the ionization number Z. This suggested that thermal equilibrium that could not have produced these energy levels. It was proposed that the generation of fast ions had to be electrodynamic in nature. This led to the discovery of the nonlinear force f_{NL} (Hora (1969a)) where a generalization of the long-known ponderomotive force was necessary with respect to the dielectric response (optical constants) of high temperature plasmas. For full understanding of the keV ions, the concept of ponderomotive self-focusing was proposed (Hora 1969b) thereby explaining the threshold P*.

Another insight was from relativity (Hora 1975a), leading to the first publication regarding MeV ions (Luther Davies et al. (1976)) explaining the large number of fast ions with energies ranging from the MeV range and up to GeV (Osman et al. (2000)). The Linlor effect was most significant in understanding the nonlinear physics of lasers.

Modelling of plasma dynamics, including the nonlinear force of laser interaction, were possible relatively simple computer models, where one-dimensional numerical results at conditions of domination by the nonlinear force against thermal processes resulted in the acceleration of plasma blocks by 10^{20}cm/s^2 (Figures 10.18a & b of Hora 1981, Fig. 1 of Hora et al. (2007)). For a long time, this acceleration could not be measured because the necessary condition of one-dimensional, plane or two-dimensional geometry was prevented in experiments due to relativistic, self-focusing generating laser beam filaments, with extremely high intensity, generating ions up to energies in the GeV range. It was not until 1996 that KrF lasers produced pulses with the Szatmari-Schäfer method (Szatmari (1994) of about 0.5 ps duration and terawatt (TW) power. This enabled the very high contrast ratio that is necessary for suppressing prepulses by more than a factor 10^8 until about 10 ps before the TW pulse interacts with the plasma.

Sauerbrey (1996) discovered by the Doppler spectral-shift experiment, that plane plasma blocks had been generated by an acceleration of 10^{20} cm/s^2 as calculated by an Australian team led by Hora (1981). The exact agreement with the nonlinear force theory was evaluated in detail (Hora et al. (2007)). Using high contrast "clean" laser pulses led to the suppression of relativistic filamentation as seen from the x-ray emission (Zhang et al. (1999)) or directed fast plasma block emission with space charge neutralized ions of extremely high current densities (Badziak et al. (1999)). The crucial paper for the explanation using the nonlinear force model (Hora et al. (2002), for ease of reference reproduced here as an Appendix) of a non-thermal, electrodynamic transfer of laser energy directly into plasma motion was reported after discussion with a number of experts in this field.

The repetition of the ultra-high acceleration (Sauerbrey (1996)) was rather difficult in view of the needed extremely high contrast for the laser pulses and the detailed properties involved. It was possible with a contrast of 10^9 and even with some lower laser pulse intensities to measure a block acceleration of $2x10^{19}$ cm/s^2 (Földes et al. (2000), Veres et al. (2004)) which could be analysed by nonlinear force action (Hora et al. (2011a)).

The importance of the many years research and interpretations (Osman (2005), Cang et al. (2005), Hora et al. (2007), Hora (2009a), Hora et al. (2011c)) can be directly seen form the ultra-fast acceleration where the nonlinear force is acting on the electron cloud within the high-density plasma instantly converts optical energy with nearly 100% efficiency into plasma motion without thermal effects where the inertia is given by the ion cloud being electrostaticly coupled to the electrons. This is the most straight forward evidence of the nonlinear force interaction process. The fundamental difference between nanosecond and picosecond (including attosecond) interaction (Krausz (2011)) is visible in the resulting ultra-high acceleration.

After the ultra-high acceleration of the then space-charged neutral plasma blocks with a ion current density of more than 10^{11} Amps/cm^2 is generated, this can be applied in the side-on ignition of solid density fusion fuel according to an updated theory by Chu (1971) and with optimized conditions (Osman et al. (2007)) by producing a fusion flame with velocities above 2,000 km/s at ignition of deuterium-tritium (DT) (Hora (2009a), Hora et al. (2011a & b)). A significant turning point in the generation of fusion energy followed when the results with DT fusion (Oliphant et al. (1934)) were extended to the nuclear fusion of protons (normal light hydrogen) with the boron isotope 11 $H^{11}B$) where less radioactive radiation is produced by the reaction, within the reactor and wasted than from burning coal per unit of generated energy. Prior to that, the experience had been that laser fusion of $H^{11}B$ is about five orders of magnitude more difficult than of DT (Hora (2009a)) and therefore was thought to be impossible. However, with the new method of ultra-high acceleration of plasma by laser, the side-on block ignition of uncompressed solid $H^{11}B$ is reduced to less than one order of magnitude more difficult than that of DT (Hora (2009), Hora et al. (2009b)). This very recent result that could lead to nuclear fusion energy with less radioactivity generation than burning coal (Hora et al. (2010)) was reported at the Royal Society of Chemistry in London (Li (2010)), referring to one of the leaders of the National Ignition Facility (NIF) laser fusion project in Livermore near San Francisco that “this has the potential of the best route to fusion energy”.

The fast interaction processes of picoseconds are an essential advantage for controlled fusion energy production because it avoids thermal mechanisms with their characteristic delays and energy losses. The fast, ultra-high acceleration is based on direct and instant conversion of laser energy into plasma motion by the electrodynamic forces under negligible heating[5].

Now, for the first time, hydrogen-boron ($H^{11}B$) fusion may become possible (Hora et al. (2009a), (2010), Li (2010)). Although this option was considered early on by a number

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[5] The advantage of fast processes is to reduce the problems of complex systems as noted by Edward Teller in 1952 (Teller (2001)). Teller observed that the theory of hydrodynamics, as it stood in 1890, suggested that it should not be possible to fly. After aircraft were flying, phenomena such as turbulence and other processes of complex systems came to be better understood. The stabilization of complex systems used in this new field was pioneered by May (May (1972), (2011a), (2011b)) and referred to in the context of Teller’s views regarding the difficulties of controlled fusion energy generation (Hora (2011b)).

of research teams (Hora (1975b), Miley (1976), Hora (2011b)), previously it had not been thought to be possible. The potential breakthrough with H^{11}B is that an approach based on ultra-fast plasma block acceleration and nonlinear force driven side-on ignition may be able to overcome a fundamental problem with DT fusion (Labaune (2011)). The problem is this: if DT fusion were to supply the Earth's energy needs, each year, 2,745 cubic meters of tritium would be needed. Currently, the only way that this could be sourced is from the equivalent amount of lithium. This amount of lithium is simply not available from current commercial sources at a resonable cost (Koonin (2011)). A further problem is that the only established processes for producing tritium from lithium release free neutrons. The neutrons decay into harmless electrons and protons (with a half-life of 881 seconds) but only if they do not interact with other materials. Interacting with other atoms could produce large amounts of radioactive waste.

Utilising fusion of H^{11}B might eventually provide a solution to both problems The current method of side-on ignition with nonlinear (ponderomotive) force driven plasma blocks by ultrahigh acceleration is still embryonic. Commercial production of energy using nuclear fusion will require drawing upon the rich knowledge of plasma physics that has been developed in the last 70 years. The current well-advanced method of nanosecond laser compression for fusion using the world's largest laser (Campbell (2005), Moses (2010), Glenzer et al. (2011)) is of great importance as well as all what has been and will be learnt from magnetic confinement fusion. This achieved a the highest fusion gains reported so far with the JET experiment (Keilhacker (1999)) of an uninterrupted continuation of neutral beam fusion on larger scale is open which scheme follows well (Hora (2004); (2005)). Also the stellarator system will be important for further exploration of plasma physics after the essential breakthrough made by Grieger et al. (1981). Some new orientation in view of the nonlinear force interaction, the ultrahigh accelerations and the involved ignition could well become important developments within the existing capacities on plasma research including a concentration of several smaller activities from the past to which the contributions of team of the University of Western Sydney will be counted.

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From left to right: Dr. S. Jablonski (Poland), Prof. Jan Badziak (Poland), A/Prof Carmel Coady, Prof. Heinrich Hora (Australia), Dr. Wei Hong (China), Mrs. Rosemarie Hora (Australia), Dr. Yu Cang (China), Dr. E. Michael Campbell (USA), Dr. Hui-Chun Wu (China), Dr. Scott Wilks (USA), Dr. Sebastian Glowacz (Poland), Prof. Dieter H.H. Hoffmann (Germany), Dr Frank Stootman (Australia) Dr. Don Neely (Australia), Dr Weimin Zhou (China), Dr Reynaldo Castillo (Australia) and Dr Frederick Osman [front] (Australia).

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Appendix

This appendix is an extract from conference proceedings at which the fundamental science underlying this approach was reported.

A full copy of the paper from the paper (Hora, H. Peng, H. S. Zhang, W. Y. Osman, F. (2002) New skin depth plasma interaction by ps-TW laser pulses and consequences for fusion energy; Proceedings of the International Society for Optical Engineering; ISSU 4914; 42-53) *is available on the Society's website.*

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New skin depth plasma interaction by ps-TW laser pulses and consequences for fusion energy

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Abstract

A new type of MeV ion generation at laser-plasma interaction has been measured based on the observation [1] that ps neodymium glass laser pulses of about TW and higher power do not produce the relativistic self-focusing based very high ion energies but more than 50 times lower energies. On top the strange observation was reported that the number of the emitted fast ions did not change at variation of the laser focus intensity by a factor 30. This can be explained by the effect that without an irradiating prepulse, a pure plane geometric skin layer interaction mechanism occurs. Neither relativistic self-focusing is possible nor the process of thermalization of quiver energy by quantum modified collisions. Following our conclusions about the difficulties for the fast ignitor concept of laser fusion, we can explain how these mechanisms can be used for studying the self- sustained fusion combustion waves as known from the spark ignition at laser fusion. We further expect an improvement of the conditions for the experiments with the highest laser fusion gains ever reported where even no pre-compression of the fusion plasma was necessary

Introduction

Lasers up to the petawatt power range and ps pulses opened a new challenge in physics. A basically new introduction of laser beams with targets was observed when pulses with powers above about TW and ps or shorter duration were irradiated. An essential difference in the emission of x-rays or vey energetic ions was dependent on the prepulses before the main short pulse arrived. While the Mourou technique for producing the very intense short pulses [6] was an essential breakthrough in the laser development since a few years, the differentiation by prepulse conditions pioneered by Jie Zhang [7, 8] is a further reason for very unexpected observations as will be shown in the following from examples of ion emission. A first interpretation of these measurements by omission of the usual relativistic self-focusing was initiated by Wang Long [9]. It turned out that the earlier known nonlinear phenomena mostly including ponderomotive and relativistic self-focusing or conditions for energetic x-ray emission in the irradiated plasmas are basically different and modified as can be concluded from the following reported theory of skin layer interaction process [2, 3, 10]. The key experiment which led to this new interaction experiment is that of Badziak et al. [1] which differs essentially from the numerous observations as e.g. [11]. In order to confirm these unusual observations, new very specific experiments were performed [2, 10] as summarized in the following on which the new theoretical results are being based.

The consequences for fusion energy generation by lasers consist in a possible clarification and refinement of the conditions of a new type of experiments which were first published by Norreys et al [5] which arrived at the highest fusion reaction gains ever published. Irradiation of 1.3 ps neodymium glass laser pulses of 6 to 15 TW on deuterium or deuterated polyethylene without any pre-compression produced a fusion gain of 3% when converted to deuterium-tritium and assuming uniform spherical neutron emission. This has to be compared with the highest gains of 1.8% measured with usual spherical irradiated on glass micro-balloons filled with deuterium-tritium gas [12] where neutrons were produced by 35 kJ frequency tripled neodymium glass laser pulses in the ns range optimized to the conditions of adiabatic volume compression [13].

The ps experiments [5] are closer to the conditions with a self-sustained fusion reaction wave front in contrast to the mentioned volume compression case [12, 13] which may lead to volume ignition at higher laser energies [13, 14] though the main aim in laser fusion is not volume ignition indeed correspond to the interesting general conditions of equilibrium of radiation, electron and ion transport from the hot into the cold plasma. The conditions of the ps experiment [5] may be different to the fusion wave conditions of spark ignition [16]. For a clarification we first outline preceding publications before discussing to the details of the new results of prepulse effects for ps laser plasma interaction.

Editor's note

There have been a number of theoretical approaches that have led to the current understanding. These are mentioned briefly below and the reader is referred to the original work for details. Several key figures mentioned in the next section are included here.

- *Fast ion interaction with plasma*
- *Nonlinear force theory for laser acceleration of plasma blocks*

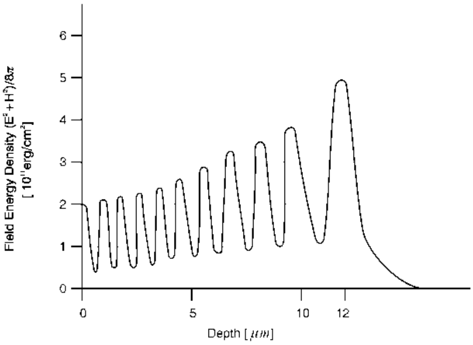

Fig. 1 Genuine two fluid calculation [21] of the electromagnetic energy density $(\mathbf{E}^2+\mathbf{H}^2)/(8\pi)$ *of the neodymium glass laser field of* 10^{16} *W/cm*^{2} *intensity after one ns in a deuterium plasma initially at rest and 100 eV temperature with an initial electron density of* 5×10^{20} *cm*$^{-3}$ *at the plasma surface increasing linearly on the depth where the critical density* 10^{21} *cm*$^{-3}$ *is reached at a distance of* $12\mu m$ *from the surface. The maximum corresponds to an electric field amplitude 3.1 times higher than the vacuum value due dielectric swelling.*

- *Analysis of ion energies from laser irradiated targets*
  - *Fastest ion group*
  - *Second fastest ion group*
  - *Anomalous low ion energies at ps irradiation without prepulse from the experiment of Badziak* et al.

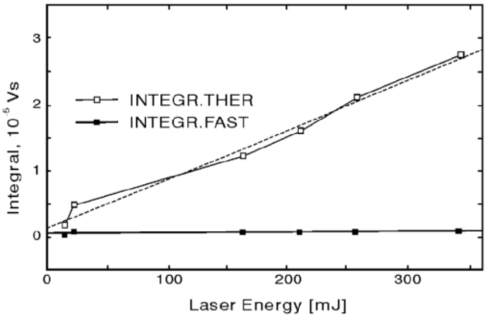

Fig. 2. Badziak et al *[1] effect of anomalous ion emission: Number of (integrated signal) emitted fast and thermal ions from a perpendicular irradiated copper target at neodymium glass laser irradiation of 1.2 ps depending on the laser pulse energy focussed to 30 wave length diameter with suppression of a prepulse by* 10^8 *for a time until less than 1 ns before the main pulse arrived.*

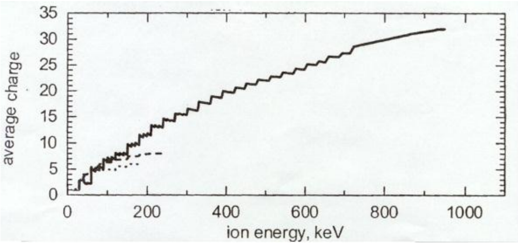

Fig. 3. Measured Charge Z and energy of the emitted fast ions from gold target irradiated by a 0.5 ns neodymium glass laser pulse of 0.7 J. energy and a focus diameter of $30\mu m$ *together with the emitted oxygen (dashed line), carbon (dotted line) and hydrogen ions [10].*

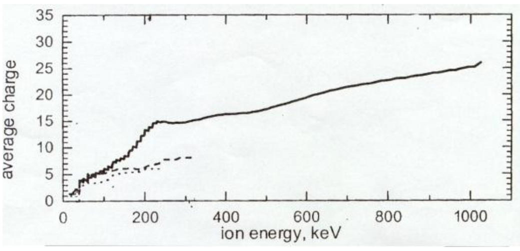

Fig. 4, Same as in Fig. 3 at the same irradiation geometry with 1.2 ps – 0.7 J laser pulses [10].

Skin layer theory for laser plasma interaction

The following explanation the few hundred times lower energy of the fastest gold ions in the 1.2 ps cases is considered as a result of a skin layer mechanism. In the experiment [10], an aspect ratio of less than 10^{-8} for the prepulse until less than 100 ps before the main pulse: no plasma could then have been produced. Only for the following 100 ps, the prepulse aspect ratio was less than 10^{-4}. It can be estimated from plasma hydrodynamics that this last part of the prepulse produced about 5 to 10 μm thick plasma in front of the target which is located in the beam focus as confirmed by the maximum x-ray emission depending on the focusing distance [1]. In view of the 30 μm diameter of the beam, the thin plasma layer in front of the target will not permit relativistic self-focusing from all knowledge of the relativistic self-focusing theory [41-42].

There seems to be an important interplay with the 10 μm thick plasma in front of the target through which the plane laser front is penetrating up the critical density and accelerating the plasma corona against the vacuum as a plane block as described in Fig. 1 while the plasma behind the critical electron density is irradiated only within the skin depth. This block of plasma of the volume of the skin depth times the whole 30 μm focus cross section is moving towards the target interior without filamentation as a plane plasma block as described, Fig. 4. The laser beam within its whole 30 μm cross section can penetrate into the superdense target plasma only one skin depth, i.e. less than or about an effective (dielelectric prolonged) wave length deep, comparable to the plane geometry calculation of Fig. 1 for the depth between 12 and 14 μm. This is an optical property and therefore independent on the laser intensity. This optically determined skin layer volume is nearly independent of the laser intensity therefore the number of fast ions does not vary when the laser intensity is changed by a factor 30 with the result that the number of fast ions is constant as measured (Fig. 2). On top, the 10 μm prepulse produced plasma layer in front of the target produced a dielectric swelling S as seen in the following by a factor of about 3.5. At these conditions the maximum electron quiver energy ε_{osc} of 19.5 eV in vacuum for the measured maximum ion energy at 300 mJ laser pulses at 8×10^{16} W/cm^2 intensity in is increased by the factor of swelling S. These conditions provided then the ideal plane wave geometry (without any filamentation) for a plane geometry acceleration of the electrons against the laser beam by the multiple of the swelling to produce the MeV maximum energy of the Au^{+26} ions

$$\varepsilon_{imax} = \varepsilon_{osc}(S-1)Z/2 \qquad (22)$$

in rather good agreement with the measurement. The details of the swelling and the temporal development of the whole nonlinear kinetics has still to be refined but this is supported by the experimental fact that the measured maximum energy (Fig. of the O^{+8} ions of 310 keV (Fig. 4) very accurately agrees with the result of the maximum energy of the Au^{+26} ions of the higher Z-ratio indicating for both ion species the fully identical collisionless and mostly electrodynamic nonlinear force acceleration mechanism by the whole volume of the block of the electron cloud. The very minor modification of this dynamics by the collision was shown [31, 34] in numerous computations using the genuine two-fluid real condition hydrodynamic code including the Poisson equation for the Coulomb effects and the nonlinear generalization of the collision frequency at high laser intensities.

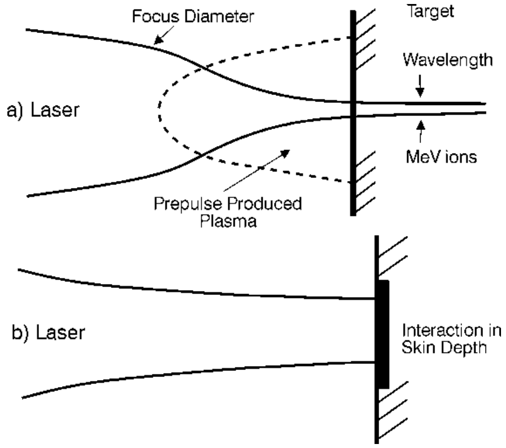

Fig. 6. Scheme for demonstration of the essential different geometry of the laser-plasma interaction volumes for subsequent volume-force nonlinear electron acceleration with separation by the ion charge Z. In case (a), the pre-generated plasma before the target causes instantaneous relativistic self focusing of the laser beam to shrink to less than a wave length diameter with very high acceleration due to the strong gradient of the laser field density. In case (b), the nearly not present or too thin plasma in front of the target permits only interaction in the skin depth with much lower ion energies but nearly ideal plasma geometry conditions treated in many details [31, 34].

The thickness of the effective Debye sheath for the electrons precursing the ions,

$$\lambda_{Deff} = 743\left(T_{eff} / n_e\right)^{1/2}\ cm \qquad (1)$$

can be estimated to be in the range of few 100 nm showing that the double layer "Coulomb acceleration" mechanism is still covered by the one fluid hydrodynamic description of the experiment of Fig. 4. Fig. 5. shows schematically how the block of accelerated plasma moving toward the laser and that toward the plasma interior have the Debye double layer surface layer of leading electrons.

The difference between the geometry self-focusing and the skin layer case is shown schematically in Fig. 6. After the clarification that the plane skin layer model explains the maximum gold and oxygen ions for the ps interaction without relativistic self focusing, we can explain also the result of Fig. 2 that under these ps irradiation without prepulse, the number of the accelerated fast ions form the intensity independent skin layer volume of Fig. 6b is constant too. The deposited energy is proportional to the laser energy and the quiver energy of the electrons resulting then in the linear increase of the maximum ion energy on the intensity as measured, according to $\varepsilon_{imax} = I$.

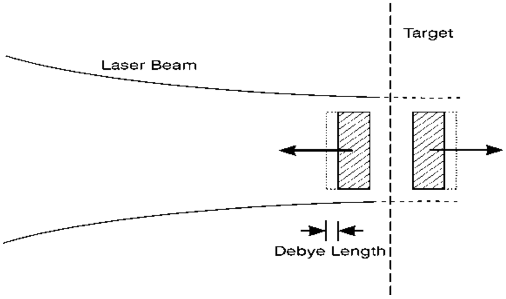

Fig.5. Scheme of skin depth laser interaction where the non-linear force accelerates a plasma block against the laser light and another block towards the target interior. In front of the blocks are electron clouds of the thickness of the effective Debye lengths, Eq. (1).

The transition of our skin layer model towards the relativistic self focusing conditions has been seen before [8] in experiments when ps laser pulses irradiated solid targets at a systematic variation of a prepulse of an intensity where plasma is generated [7]. If the prepulse is at a too short time τ_p before the main pulse, the x-ray emission is very low in agreement with the skin layer model. As soon as the τ_p was 70 ps before the main pulse, the x-ray signals were strong and ion energies appear as expected from the relativistic self-focusing in the high-density plasma. This is due to the fact that the prepulse has produced a high-density plasma plume about two times the beam diameter above the target. This agrees with the more specific experiments for clarifying the skin layer mechanisms, presented here as a fundamentally new explanation.

For further studies it should be mentioned that it seems that the $10\,\mu m$ deep plasma in front of the target may be essential for the moderate swelling for providing the dielectric nonlinear force explosion of the two plasma blocks of Fig. 5. If an absolute exclusion of a prepulse is performed. J. Zhang expects an aspect ratio of 10^{-12} by using the second harmonics of this advanced Ti-sapphire lasers now up to 100 PW operation [8]. The conditions may appear as theoretical discussed by Mulser [30] where very low x-ray emission may be expected in connection with a peripheral drive of a fast ignitor [25]. Instead of the swelling produced dielectric expulsion of the plasma block of Fig. 5, only the ordinary radiation pressure mechanism (see Fig. 5-1 of Ref. [31]: no deconfining acceleration) will drive a plasma block of the skin layer with the ordinary radiation pressure into the depth of the target and not the increased radiation pressure due to swelling.

Consequences of the skin layer laser plasma interaction theory

Though a number of details have to be clarified for the skin layer interaction, the following new aspects for the application of the >TW-ps laser pulses with or without prepulse control may be concluded.

Laser driven ion sources

The fact that laser produced plasma with powers above P* produce million time higher ion current densities of proton beams [48] or of very highly charged ions than known from classical ion sources [2] is at least encouraging for using a laser ion source with 100 J – 10 ns laser pulses as a very competitive solution for very heavy ions in the large hadron collider (LHC) at CERN against the standard ECR source. The problems of the feeding in of the initially highly charged ions into a quadruple and linac are now under control [49] after the basic advantages of this technique had been elaborated [38]. Next step Ti-sapphire TW-PW sub-ps laser with a rather high repetition frequency up to 1 Hz are of a relatively modest costs in future. After further clarifying the parameters of the skin layer interaction. It should be possible to produce the highly charged ion blocks moving with rather low internal temperature but with high ion energy in a very directed way into the pre-amplifiers of the accelerators with an enormous increase of accelerator properties and initially very high charged heavy ions.

Nuclear physics applications

Very recently it was discovered that laser pulses of ps or shorter duration with powers of few TW only produced highly charged ions and gammas of up to 100 MeV energy [50]. In most of these experiments it was not necessary to carefully control the prepulses. If the mentioned highly energetic particles and gammas were produced using relatively low laser powers of few TW only, it can be assumed that no high aspect ratio may have been used and that relativistic self-focusing has produces the generation of the very intense and high energy particles for the short time of ps leading to a basically new dimension of nuclear research.

Laser fusion following the experiment of Norreys et al.

The very high gain laser fusion experiments of Norreys et al [5] was mentioned in the beginning. We discuss now the consequences for possible improvements using the presented skin layer interaction. Assuming similar conditions for both experiments of 1998 and 2001 [5, 47] we explained why relativistic self-focusing was avoided and only the quiver-collision hot electron generation produced the half GeV lead ions. Very probably a rather stronger prepulse was involved. If the prepulse could be controlled to a very last stage as in the Badziak et al experiments [1, 10] or by the techniques of J. Zhang [7, 8] it may be possible to reduce the hot electron generation and to achieve the nonlinear force driven highly directed block motion of plasma (Fig. 5). For generation of reaction front for ion interpenetrating [4], ion energies of about 100 keV are optimized. Instead of the conditions for half GeV ion acceleration [47] one may defocus the high aspect ration ps pulse to a large cross section with PW pulses with final intensity of few 10^{17} W/cm^2 specified with a modest swelling similar to Fig. 1. The block of DT plasma towards the target has then a (space charge neutralized) ion current density of 10^{10} Amp/cm^2 such that pulses of about 10kJ will reach the condition of few 10^6 J/cm^2 for generation of the reaction front as explained before [4]. This may then lead to a very high gain energy production even possible for a combination with the dream fuel pB(11) [51].

It is no question that for such a scheme an enormous amount of work is necessary to clarify the just elaborated skin layer interaction mechanism [2, 10] as initiated by the experiments by Badziak et al [1] and Zhang et al [7] and the special attention to prepulse control and necessary high quality picosecond (or shorter) laser beam generation. The computational analysis of the swelling and the nonlinear force acceleration as expressed in Fig. 1 is then a further extensive task. Furthermore the earlier described interpenetration process initially designed for the ANTARES carbon dioxide laser [4] and now open for the laser beams from the Mourou technique [6], needs a much more detailed clarification. Summarising this all it is by far not certain that the just explained extension of the Norreys et al experiment [5] along the described lines will lead to the kings way for the laser fusion power station but it seems to be interesting to consider this possibility apart from unique new physics to be gained with this research.

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