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LASERS, NANOTECHNOLOGY AND ENERGETICS

In the last 60 years one of the instrumental technology, developing with extreme speed has been the laser. We have today „lasers" from the microwave to the ɣ-ray frequency range, from continuously radiating to the attosecond long pulses and from nanowatts to multipetawatt power. The spectrum of the field of laser applications is also broad, practically all areas of human activity are containing some forms of laser applications.

The same applies to nanotechnologies. *Richard Feyman* spoke already in the 1950-ties about many things, which *„may exist at the bottom"*, when he introduced the concept of nanosciences. Since that time the number of publications, as well as the applications of continuously increasing number of new scientific results is increasing with nack breaking speed. It is expected, that soon nanotechnology enters practically into all technological sectors as basic or key technology.

And how these developments may influence the solution of our energy problems? For 2050 the forecast is the need of 10 TW of new, renewable energy production and it should be cheap. This problem can not be solved with the technologies used today. Most of our resources are today the fossible ones (coal, oil, gas) and we should put all our efforts to minimize their use. The real potential reserve, the sunshine brings to our planet 10000 times more energy, than used by mankind today, but the exploitation is far from optimal. In a selected part of the World nuclear energy (fission reactors) play significant role in electric energy generation and this source is going to remain significant in a transition period of a few decades.

There might be a potential other energy source of nuclear type, namely fusion, with a practically unlimited fuel resource in the seas, namely heavy water. And this material, behind solar radiation might become our main energy supplier in the not too distant future. And there is an other argument to favour the use of this source. Our general experience is, that our best technologies are those, where we succeed to copy processes in nature and fusion is one of them. The brutal use of this energy source is the hydrogen bomb, but there are several attempts in different research laboratories already today to bring this process down to controlled energy production.

To do this there are practically two types of approaches to solve the problem of fusion reactors. The first one is to keep a low pressure gas of the fuel (a mixture of deuterium and tricium gas) by external magnetic field in a closed volume (e.g. a torus shaped vacuum vessel) and heat it up to the order of 100 million degrees, where the D and T nuclei collide, fuse and a helium nucleus is born. The mass of this nucleus is smaller, than that of the two colliding nuclei and the mass difference transforms into energy (Einstein: E=mc2, where E is energy, m is mass and c is the velocity of light). A typical facility to explore this process is the multibillion Euro ITER, under construction in Southern France.

The second version aims to achieve the needed high temperature of the DT fuel by squeezing a solid spherical fuel pellet. This process brings the nuclei near to each other and at the same time warms up the material to the needed temperature. The squeezing is the result of the surface evaporation and the resulting reaction force. This is achieved with intense laser light. The most widely known attempt to realize this process is the National Ignition Facility (NIF) in the US, using 192 laser beams, each with several ten nanosecond long pulses to squeeze the spherical sample with multimillion Joule laser energy. This several billion USD and stadium sized facility, however, has several basic problems. One of them is the instabilities in the squeezing process due to it' s „slow" speed. The other problem is, that only a small central part of the DT pellet is expected to fuse.

Our attempt is to overcome these problems by a novel solution combining some results borrowed both from nanotechnology and particle physics.

Since in the long term, as stated above, the clean and massive energy supply is vital for the future of humanity on the Earth, with limited available material and territory, the best choice is fusion energy (which, as stated above is the source of the solar radiation). The ideas, achievements and recognized obstacles of the Inertial Confinement Fusion (ICF) studies motivate our research too. Fusion is the cleanest, most concentrated energy source. Its fuel, Deuterium and Tritium (DT) is well available on Earth. The direct reaction product, Helium, is more complex than the fuel, so that the process satisfies *Erwin Schrödinger*'s physical definition of sustainable development.

However, ICF research and development today is hindered by the hydrodynamic instabilities occurring due to the indirect ignition of the DT pellet put into a "hohlraum" and with the intense compression of the target fuel. These obstacles arise from the basic intention to achieve ignition by extreme "adiabatic" compression. Due to the observed difficulties and the slow progress of the ICF research, the interest is shifted now to studying rapid structural transition studies (in the femtosecond time domain) in different systems, which are important for advanced high tech applications, and for astrophysical processes, i.e. generally for investigating lower-energy, but highly dynamical changes in bulk materials.

We work on a radically new approach, which combines recent advances in different fields of physics: first – the regulation of radiative energy deposition by plasmonic nano-shells. and second – detonations in relativistic fluid dynamics. These two ingredients are expected to lead to a new groundbreaking advance in a third field: uniform, stable, rapid dynamical transitions in a macroscopic volume of materials. This method is applicable in the fusion process but in addition also in several other processes, including melting and structural changes of different materials, combustion in gas turbines and in rocket propulsion, and other extreme dynamical processes too.

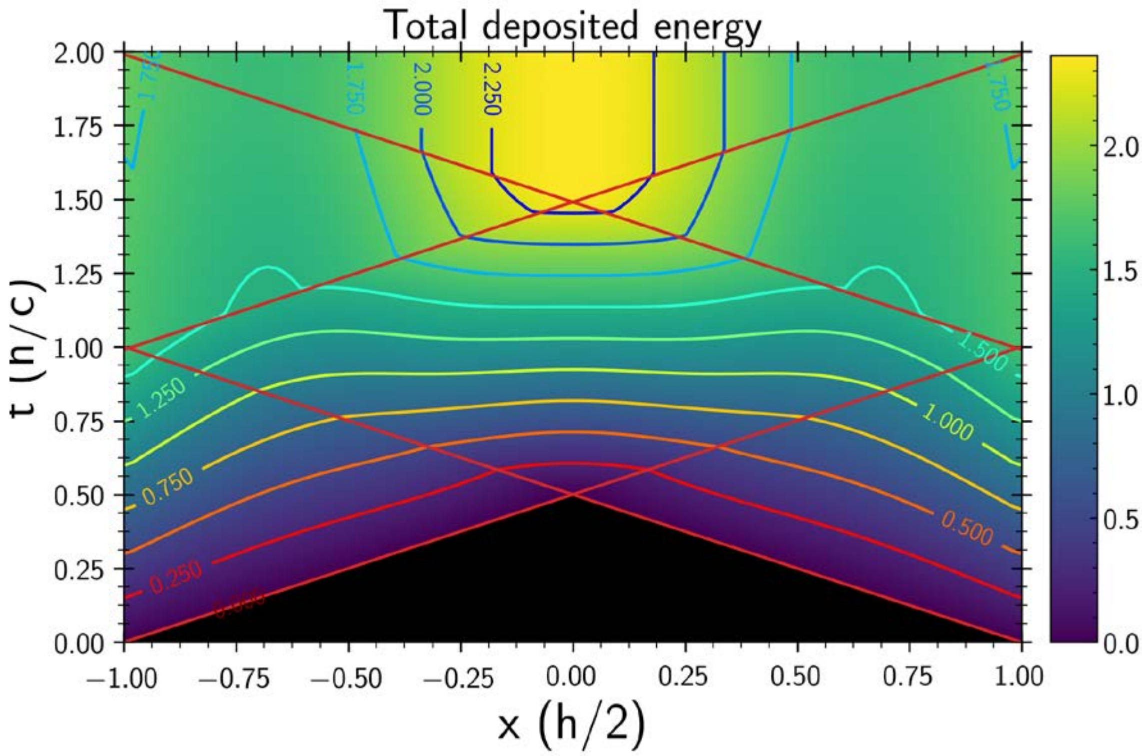
When regulating the target absorptivity by nano-particles (nano-antennas), one might enhance the light absorption by several orders of magnitude, and the process is characterized by extremely fast timescale of 10 – 100 fs. Furthermore, due to an other phenomenon, namely multiphoton quantum excitation the photoluminescence effect leads to a blue-shifted radiation, which accelerates the heating of the pellet even more.

Our second proposal originates from the high-energy subatomic theory of extreme ultra-relativistic heavy ion reactions, where relativistic fluid dynamics is developed, to provide significant theoretical advances. It is shown that in relativistic systems, so-called time-like detonations can happen, i.e. simultaneous transitions in a whole volume of the bulk material. This has been proven theoretically and experimentally in the field of high-energy heavy-ion collisions, while in the traditional fluid-dynamical treatment of fast transitions in ordinary materials has never been discussed. Our hope is to explore this process too.

With this method, rapid volume transition or burning can be achieved, as fast as the penetration time of the light across the pellet. Since the light absorptivity can be increased by several orders of magnitude using the plasmonic nano-shells embedded in the target fuel, and this allows making the transition practically simultaneous in the whole target volume.

Our envisaged breakthrough is to achieve rapid, effective, simultaneous volume transition or combustion (or fusion) in the target, avoiding instabilities. By properly choosing the target material and laser beam parameters (power, duration, profile) one can study the fusion process, melting, vaporization, combustion and ionization transitions, as well as subsequent evolution of heated and compressed matter.

Our preliminary calculations indicate that our goals can be achieved. A scale invariant test of rapid transition is shown in the figure.



Laser beam from both sides along the x-axis deposit energy in the flat target. The deposited energy in units of the total amount of energy from one side, Q. The irradiation lasts for a period of h/c, where h is the target thickness, and c is the speed of light in the target material. The time is given in units of (h/c). The total irradiated energy from one side is Q is deposited during the irradiation pulse length t=h/c. The deposited energy is decreasing in time along x inward. This is balanced by the increasing absorptivity of the implanted nano-shells, so that the deposited energy in the initial space-time segment is approximately uniform. The absorptivity depends on the number of nanoshells increasing with the depth in the target. Then in the next space-time segment, where the target matter is reached from both sides the deposited energy fraction suddenly doubles. This doubles the energy deposition in the spatially central layer of the flat target. In the above optimization, it is assumed that the implantation density distribution in the target is Gaussian. The red lines indicate the light-cones, the trajectories of the beginning and end of the trajectories of the imploding light fronts in the space-time. In the final space-time segment, the deposited energy is small, as most of the energy of the light fronts were deposited earlier.

The two ingredients of the proposed new method are well known and tested separately. The theory of relativistic detonations was described first 30 years ago and tested in the field of relativistic heavy ion physics in the last two decades extensively. Its use for subatomic energy releasing processes was described four years ago. This is needed to achieve simultaneous whole volume transition, thus preventing all mechanical instabilities. The increased absorptivity by plasmonic nano-shells was discovered also about 15 years ago. The possible combination of these two ingredients was described recently by us, but the optimization calculations are still under way, and the experimental verification of this new approach is still to be performed. Within this project, we plan further theoretical work and experiments in the frame of a newly launched Hungarian research programs.

Prof. Dr. Norbert KROÓ, Past Secretary General and Vice-President of the Hungarian Academy of Sciences (HAS), member of the Scientific Council of the European Research Council, founding director of the Research Institute for Solid State Physics and Optics of HAS. Honoris Causa Professor Doctor of the Roland Eotvos University (H). Former president of the European Physical Society and member, honorary member or doctor of several distinguished scientific institutions and universities. (Academia Europaea, Spanish Royal Academy, Jordanian Royal Scientific Society, European Academy of Science and Arts, Euroscience, etc.). His latest decorations are: the Alexander von Humboldt Research Prize (D), the Wallis E. Lamb Award for Laser Physics and Quantum Electronics (USA), the Commander of the Order of the Lion Award (Finland), The Middle Cross with the Star Award of the Hungarian Republic (H), the Charles Hard Townes Distinguished Lecturer Award (US) and the Hungarian Prima Primissima Prize for Science. He is Honorary Member of the European Physical Society and the Institute of Physics (UK). He was member of the High Level Expert Group on Digital Libraries (EU) and the European Research Advisory Board, Chair of the Research Infrastructure Expert Group of the EU and the European Science Foundation. Adviser of several international and national research institutions. One of the founders of the World Science Conference and the World Science Forum, Hungary. His research fields: neutron physics, laser physics and quantum optics, plasmonics. He has published more than 320 scientific papers, 4 books and is the owner of 41 patents.