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空间能量传导通道模型的实验和理论成果

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摘要:给出了研制空间能量传递的超长传导通道技术的实验和理论工作结果。分析了高重频脉冲激光系统和这一项目中的最重要的组件。基于创建长距离能量传递传导通道的思想,讨论了光学系统和尘埃等离子体,研究了测试等离子体导电性的实验方法和新的测量数据。最后,阐述了“脉冲发生器”的新应用。

关键词:传导通道;脉冲激光系统;尘埃等离子体;脉冲发生器

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Conductive canal for energy delivery from space: Experimental and theoretical results of modeling

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Abstract: The results of experimental and theoretical studies on creation of a super-long conductive canal technology for energy delivery from the space are presented. A high repetition rate pulse-periodic laser system and the most important components for the project realization are analyzed. The optical system and dust plasma based the conductive canal idea for long range energy delivery is discussed in details, then, some experimental approaches to dust plasma conductivity tests and new data of measurements are investigated. Finally, new applications of "Impulsator" program suggested are highlighted.

Key words: conductive canal; pulse-periodic laser system; dust plasma; impulsator

1 “Ionosphere-Earth” and “Clouds-Earth” condensers as the sources of energy

There are no any other forms of energy more abundant than the sun irradiating energy. The sunlight bathes us in far more energy than that we could ever need — if we could just catch e-

nough. The sunshine on the solid part of the Earth is about 120 PW and total value for the globe is 274 PW. The power density of solar energy on the orbit of Earth is very constant and equal to 1.37 kW/m². The total power needed by the humans on Earth is about 16 TW. By 2020, it is expected to grow up to about 20 TW. At the same time, well developed countries plan for 2010 budget calls for doubling the country's re-

renewable energy capacity in three years. What is going on in our days in the area of renewable energy production in the world. "Nevada Solar One" based on an oil heating technology, for example, has demonstrated 21% of sun's rays into electricity. The layering compound technology based on GaInP/GaInAs (PV) has demonstrated to be 40.8%, but the cost of that super modern technology is huge to 10 000 USD/cm² or even more than that. At the same time, the standard PV panel technology efficiency is as high as 23%. 160.9 km × 160.9 km (100 mile × 100 mile) of PV (3/10 of USA surface on the globe) could electrify the entire country, but the cost of that technical operation as well looks awfully. A much smaller solar PV panel can be deployed in the space behind the dense shield of air, but to get this energy on the ground, we need an effective way to transform that energy into the microwave, electron beam, laser light or any other type of conductive canal for low loss delivery.

Well known the energy distribution of different production sources for 2006 looks like the following: renewable for the world — 343 B KW-H, nuclear and other — 932 B KW-H, fossil — 2 780 B KW-H. But for 2030 the same distribution looks very different: renewable for the world — 864 B KW-H, nuclear and other — 926 B KW-H and fossil — 3 358 B KW-H. All that really means that we are in the very beginning of the solar energy production process. Why we cannot think about the huge energies of clouds and ionosphere as a source of the energy, concentrated in the natural condensers around our planet?

During the last few years in the literature, there were published very much reliable data and results of study of so-called "jets" and "sprites" — discharges in the huge condenser "Ionosphere - Earth"^[1]. The volume of each category makes up to 1×10^4 km³. The discharge usually arises over an ocean surface. There are cases of elevated discharges. The volume of a transferable energy to the Earth can be up to several tera-

joules. A series of many discharges in the range of few minutes can be registered very often. Such events can be seen in the area of equator zone $\pm 30^\circ$. There are 280 lightning discharges per year in average take place for 1 km² of Earth surface, over three million lightning strikes every day around the world. There are 10^{10} of thunderbolts per year, or 1 000 thunderbolts per second taken place at the Earth. At the same time 20 kT explosive material (energy of 1 kg of fuel U 235) are equivalent to the energy of Ionosphere breakdown to the Earth (gigantic jet) which is up to 10^{14} J.

Another significant sources of energy are the condensers "Cloud-Earth" and "Cloud-Cloud". The greatest frequency is in tropical and sub-tropical regions of the Globe, and topping the list are: El Bagre, in Colombia (270 days per year with lightning); Tororo in Uganda (274 days); and Bogor in Java, Indonesia (283 days). The most extraordinary electrical storm is found in Venezuela, at the mouth of the Catatumbo river, where it empties into Lake Maracaibo. It can be seen during 180 nights of the year for as long as 10 hours per night and is comprised almost exclusively of eerily silent cloud-to-cloud lightning, arcing through the atmosphere at altitudes of 5 — 10 km. The sky is illuminated by these flashes as often as 280 times per hour, amounting to over one million electrical discharges per year with the intensity up to 400 000 A each. The flashes are visible up to 100 km away and have been used as a natural lighthouse for many centuries, which is also known as the "Maracaibo Beacon". The confluence of cold winds pouring from the Andes and hot, humid air rising from Maracaibo's marshlands is thought to be a major contributory factor to this unique display. Ionised gases ascend from the marshes, particularly methane from decaying vegetable matter. Each lightning bolt could light all the bulbs in South America. Now, if only mankind could find a way to harness all that sig-

nificant amount of power by its efficient delivery to the ground.

Studying of the given phenomena represents considerable interest from many points of view. The essence of the observable abnormal phenomena consists of electromechanical transformation of energy surpluses of natural electricity into mechanical and thermal energies of cyclones, typhoons and other natural cataclysms. The ionosphere can keep only certain quantity of energy. Otherwise, it dumps surpluses of an electricity through atmosphere or transforms them to the energies of storms, including even storms inside the Earth. Electric breakdown of such scale of energy can be considered as the trigger hook conducting to liberation of huge energy stored before. Using the part of natural electricity for useful purposes, it is possible to get the way to operate planet weather. It could be possible at the same time to try to cause breakdowns of the Ionosphere artificially and dump of operated water deposits in the necessary points of the globe. It is very interesting to find the way of regulation for the climate of our planet (very important after the summer event in the Europe this year) and to prevent or to reduce amplitudes of magnetic storms, earthquakes, hurricanes with the help of high repetition rate laser technology. The quantity of atmosphere electricity is closely connected with the important components of a natural complex of the planet, in a part; deducing out of operation systems of electronic maintenance, influence on astronautics and aircraft, perfection of methods of long-distance detection of objects, problems of electromagnetic influence over ecological systems and measuring devices, attempts to correct the climatic conditions on the Earth.

2 Lightning protection approaches

Powerful lasers are capable to creating the spending canals of the big length which are set-

ting down on any distances from a radiator. At relatively small energies of single impulses the lengths of canals make about hundreds of meters. Since 1970 the successful attempts of their usage were undertaken for solution of problems of interception of lightning and blocking of overload waves on electric lines^[2-4]. The traditional lightning protection systems being used currently are not always in a position to ensure the desired level of efficiency. This stimulates the quest for new approaches to solve this problem. Laser protection against lightning is one of the most prospective trends that are developed actively at present. While using this approach, it is assumed that the lightning discharge canal developed is guided towards the conventional rod of the metal lightning rod along the plasma canal formed as a result of the laser induced breakdown of the atmosphere. This method is based on the concept of an active lightning rod, when a laser beam can be used for "triggering" and guiding a positive ascending leader from the tip of a lightning rod to a negatively charged thunderstorm cloud. It is expected that in contrast to the traditional approach, the use of laser spark will make it possible to control efficiently the very process of protection from lightning, ensure the selectivity of lightning capture, and provide safety of tall objects and large areas. Conductive canal in this case is about 20—25 m long and the main advantage of the approach is due to immediate appearance of laser produced prolongation of the lightning rod. But maximum length of the laser produced breakdown in the air was registered on the level of 100 m and limited by optical method and technology of laser energy delivery into the long range focal point. Where is the way to get conductive canal of much longer length?

The same goal to produce long conductive canal has ongoing French-German program "Teramobile"^[5], based on femto-second multiphoton laser technology. The task is to get a

very long canal with very low level of electrical resistivity in comparison with the canals produced by infrared laser radiation breakdown. The ionisation of the air produced by ultra-intense and ultra-short pulse can be put to use to canal bolts of lightning. As a "Teramobile" burst propagates it to create a sort of straight filament of ionised air, which should conduct electricity. If the laser were directed toward a dark and threatening thunderhead, it would trigger a lightning bolt that could be safely ushered away from doing harm. This capacity has already been demonstrated over a distance of a few meters only with a laboratory version of lightning, and tests on a more natural scale are limited by very high filament resistivity. So, what do they do with a mobile TW laser, if it is not good enough for the lightning control purposes? One can use it effectively to study the propagation of intense laser light in the atmosphere, detect pollution, and control the parameters of fast objects in the space. Ultra-high intensity brings its own special qualities. It modifies significantly the index of refraction while it induces a focusing of the light beam along its path, the effect of the latter being to produce a self-guiding laser burst which can travel hundreds of meters. Another effect is that the luminous spectrum widens to yield a white laser whose light is composed of a wide range of wavelengths, which are important for a wide spectrum of applications.

3 "Impulsar" as a background for new technology

The well known program of creation of "Impulsar" represents a great interest, as this program in a combination with high-voltage and high-frequency source can be useful in the solution of above mentioned problems^[6]. The principle of "Impulsar" operation can be shortly described as follows. Jet draught of the offered device is

made under influence of powerful high frequency pulse-periodic laser radiation. In the experiments, the CO₂-laser or solid-state Nd YAG laser systems were used. Active impulse appears thanks to the air breakdown (<30 km) or to the breakdown of low-ionisable material vapour saturated by nano-particles of conductive materials (dust plasma), placed in the vicinity of the focusing mirror-acceptor of the breakdown waves. With each pulse of powerful laser, the device rises up, leaving a bright and dense trace of products with high degree of ionization and metallization by nano-particles after ablation. The theoretical estimations and experimental tests show that with already experimentally demonstrated figures of specific thrust impulse, the lower layers of the Ionosphere can be reached in several ten seconds that is enough to keep the high level of canal conductivity with the help of high frequency and high voltage generator^[7].

The space around globe represents a series of megavolt class condensers created by Earth surface, the cloudy cover, various layers of Ionosphere and radiating belts. With the help of the high-voltage source of trajectory trace of "Impulsar", it is possible to create a conductive canal of required length and direction. In process of the optical vehicle lifting and conductive canal following it, the breakdown characteristics of the interval with decreasing for 5 orders of magnitude (90 km) density considerably reduce, than the process must be prolonged by the expanding of micro-discharges net and develop as self-supported process in the external field of all studied interval. It is important to notice, that presence of such an orbital scale canal development technology allows us to perform a number of important experiments from the Earth surface as well as from space.

4 Dust plasma conductivity modeling

The electrical breakdown of dust plasma pro-

duced by laser radiation in the vicinity of surface of graphite, textolite (glass fabric material which is impregnated with furil, epoxy, polyester, silicone-organic or other resins), vinyl (plastic material, which unlike other plastics, can easily be recycled) ferrite (iron or iron alloys with a body centred cubic crystal structure) and permalloy (nickel-iron magnetic alloy. Generically, it refers to an alloy with about 20% iron and 80% nickel content) targets were investigated. The breakdown thresholds in dependence on the materials of the targets have been measured. The high power phosphate glass laser with an asymmetric resonator with 100% reflecting back side mirror and a ring shaped output mirror was used.

Our experimental phosphate glass laser had been operated in the modified spiking mode. It generated the radiation with $\lambda = 1.054 \mu\text{m}$. Temporal structure of radiation represents the series of flashes with envelope duration in the gap of 0.6–1 ms and total energy of pulses up to 20 J. Laser radiation has been detected as a series of high-contrast pulses traveling with the average frequency in the gap 100–200 kHz, and duration of each pulse was about 150–200 ns. The peak power of pulses was about 100–500 kW each.

The similar parameters of the electrical breakdown have been investigated for the clouds of dust plasma formed by explosion of nichrome (nickel-chromium resistance wire) with diameter 100 mm and length L of 20 cm. The values of dust plasma conductivity on its decay stage had been measured. The preliminary results of measurements are:

(1) The dust particle size for graphite, textolite and permalloy produced by the laser ablation was in the gap of 0.01–0.5 mkm. Charging voltage for condenser was on the level of 10 kV and the energy stored in the condenser is about 100 J; For the Nd YAG laser ablation dust plasma, the best results are: specific resistance

is 10 Ω/m , specific voltage of the gap breaking is 300 V/cm;

(2) For the case of wire explosion the corresponding values are as follows: the specific resistance is 10 Ω/m ; specific voltage of the gap breaking is 60 V/cm;

(3) Another approaches:

For canal produced by breakdown of CO_2 pulsed laser with conical optics: the specific resistance is 100 Ω/m ; the specific voltage of gap breaking is 100 V/cm;

For canal based on filaments produced by fs laser: the specific resistance is 0.1 m Ω/m ; the specific voltage of the gap breaking is 7.5 kV/cm;

(4) For the "Impulsar" modeling test with power of CO_2 laser about 1 kW with RR in 30 kHz, the gap value in 1.5 m, capacitor charging voltage in 7.5 kV and stored energy in 100 J, the specific resistance value is 10 Ω/m and the specific voltage of gap breaking is 60 V/cm.

Which means that 6 MV level of voltage (without taking in to account the natural field strength in the gap) is necessary for realization of conducting canal with total length about 1 km. The level of energy necessary for conductive canal creation is about 60 kJ.

Min. resistance value is very much dependable on the cross-section of dust particle sheaf, concentration and sizes of particles, the repetition rate of laser pulses, the average power of laser, the humidity of the air and many other parameters, which, more or less, are involved in to the process under consideration. It must be stated here that our new approach looks as a very promising one for hot and cold dust plasma investigations in the future.

5 Other applications

Ball and bead lightning investigation is the most interesting application for the super-long conductive canal technology based on "Impulsar"

due to the intriguing possibility for investigator to set up the stationary laboratory with variable boundary conditions for effective tests. It would appear after investigations to be done that natural ball lightning may be not one phenomenon but many, each with similar appearance but with different mechanisms of origin, different stability criteria, and somewhat different properties dependent upon the atmosphere and the environment present at the time of the event or test. Consideration of a large set of available data on such an objects during last few years led us to the conclusion that by "Impulsar" approach we can get a very powerful tool for investigation in the future of ball and bead lightning nature and to find a wide spectrum of new applications.

6 Conclusions

Powerful lasers are capable of creating the conducting canals of the big length which are settling down on any distances from a radiator. At relatively small energies of single impulses, the lengths of canals make about hundred meters. Since 1970, the successful attempts of their usage were undertaken for solution of problems of interception of lightning and blocking of overload waves on electric lines. Laser protection against lightning is one of the most prospective trends that are being developed actively in the past. It is assumed that the lightning discharge canal being developed is guided towards the con-

ventional metal lightning rod along the plasma canal formed as a result of the laser induced breakdown of the air;

Dust plasma conductivity modeling has demonstrated that high average power high repetition rate laser producing dust plasma sheaves perfectly contacted each other is a powerful tool for super-long canal production in the space. Next step of investigations is related to the same set of parameter measurements in vacuum. Successful technology development of high repetition rate pulse-periodic powerful lasers, as well as "Impulsar" technology let us to foresee the possibility of conductive canals of several ten kilometers length realization for the purpose of energy transfer for considerable distances, creation of new perspectives for mastering space, new spacecraft energy source adoption and settling of other several important problems like ball bead lightning investigation. The usage of presented in the paper technology and settling on its base the problems of renewable energy of Atmosphere and Ionosphere electricity as well should contribute to significant improvement of global ecology of the planet.

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● 下期预告

基于累加器的哈特曼-夏克波前斜率处理器

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哈特曼-夏克传感器子孔径数目越多,其波前探测空间分辨力越高。为了在资源有限的情况下,支持尽可能多的子孔径进行实时波前斜率处理,本文提出了一种基于累加器的波前斜率处理器。该处理器的运算核心是子光斑质心计算模块,根据二维图像矩计算的可分解性以及一维矩的递推累加求解方法,用加法运算代替子孔径坐标与像素灰度的乘法运算,获得灰度重心法所需的所有二维低阶矩。该模块仅由 5 个累加器组成,避免了乘法器的使用,因此资源消耗得以降低。仿真实验结果表明:对于 22×22 方形排布的哈特曼-夏克波前传感器图像,本文的结构用的是在 FPGA 内实现,在 100 MHz 的工作频率下,完成一帧所有子孔径斜率计算的延迟时间为 $0.33 \mu\text{s}$,计算误差小于 0.002 pixel ,而与传统的波前斜率处理器相比,其逻辑资源消耗减小了 40% 左右,能够在不增加额外资源的情况下对原波前斜率处理器进行升级,使其支持的子孔径数目增加一倍左右,实现波前斜率的高速、高精度提取。