

Concept of the power reactor pumped laser for technology applications

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ABSTRACT

Conception of a high-power pulsed reactor-pumped laser system (RPLS) based on new physical principles (direct nuclear-to-optical energy conversion) for the technology and space application is discussed. The development of an energy model of RPLS consisting of the ignition two-core fast-burst reactor module and a thermal subcritical laser module filled with an Ar-Xe laser active medium is reported. Some of the experimental results are also presented.

Keywords: reactor-pumped laser system, optical quantum nuclear-pumped amplifier (NPA).

1. INTRODUCTION

Despite of the broad spread of lasers in science and engineering their further usage in practice was restrained by small energy and power capacity. Creation of powerful laser systems of new generation can cause the new technology revolution in many human activity.

One of the prospective candidate as a powerful laser among existing types of the lasers is a nuclear reactor pumped laser.

The prospects of nuclear reactor pumped laser systems are defined by the unique properties of the pumping source which is based on fission chain reaction namely: huge power capacity, compactness, autonomy, possibility to pump almost unlimited volumes with active media due to the big penetrating capacity of neutrons in multiplicative media etc. These properties allow to hope to create on the base of nuclear reactor pumping powerful laser systems which may have large applications in space power beaming, space propulsion, inertial confinement fusion and technology as well as welding, cutting, surface treatments, isotopes separation and etc [1].

2. SCHEME OF THE RPLS

The optical scheme of the reactor pumped laser system based on the optical quantum nuclear reactor-pumped amplifier is shown in the Fig.1 [2]. The "master oscillator - two round trip amplifier" principle with face conjugation and harmonic generation is used there.

Scheme of NPA is presented in fig.2. Ignition reactor and laser modules are principal components of NPA. IBR-2 [3] type pulse fast reactor with a liquid metal cooling of the core is proposed to use as reactor module. Laser module is a cylindrical structure with longitudinal cavity for core and reactivity modulator of ignition reactor. The pumping section of the laser module is filled with the liquid laser active medium containing a fissile material and includes elements of a neutron moderator structure. At the side, this section is surrounded with reflector of neutrons, flanks are prepared from an optically transparent material and provide the input and output of the laser beam.

From the neutron-physical point of view the laser module is a subcritical system which provides multiplication of ignition reactor neutrons. Space-time uniformity of the neutron flux distribution is insured by using an external reflector of neutrons and by choosing an appropriate longitudinal and transverse distributions of moderator concentration over the pump section.

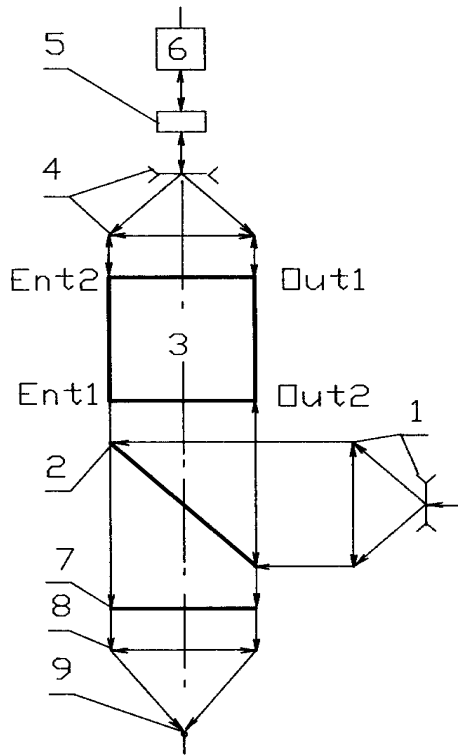


Fig.1 Optical scheme of RPLS with NPA.
1 - beam expander, 2 - polarizer, 3 - RPA, 4 - beam expander, 5 - Faradey cell, 6 - conjugation cell, 7 - harmonic generator, 8 - lens, 9 - target.

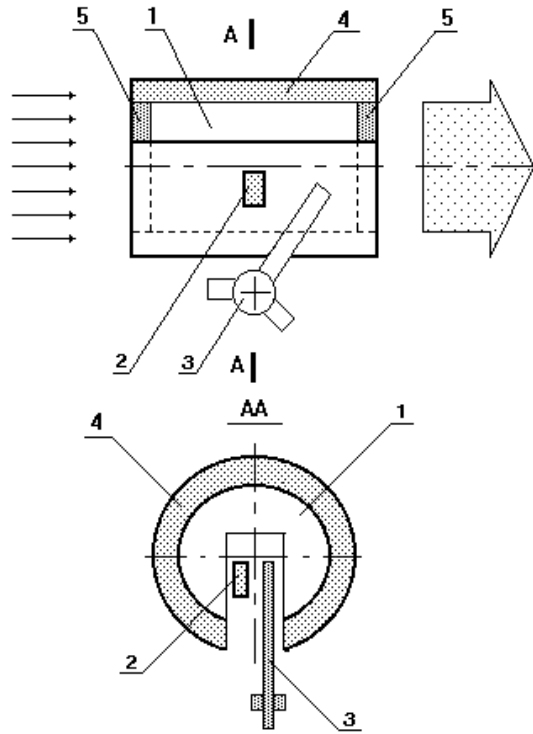


Fig.2 Scheme of the (NPA): 1 - laser module, 2 - core of pulse reactor, 3 - reactivity modulator, 4 - reflector of neutrons, 5 - optical windows.

Mathematical modeling of the characteristics of the powerful periodically acting RPL system pumped by the IBR-type reactor was made. The basic characteristics of this concept are [4]:

- Energy of the reactor pulse, MJ	2
- Effective multiplication factor of the laser module	0.9
- Pump pulse energy, MJ	8
- Efficiency of conversion of the fission energy into laser radiation energy, %	1-2
- Output energy of the RPA laser beam, kJ	100
- Frequency, Hz	1-10

3. ENERGY MODEL OF NPA

There are two the most actual problems in the research field directed to development of RPLS. The first one is an experimental demonstration of the fact that unique energy of the laser beam can be achieved by the nuclear pumping (up to 100kJ level and above). The second one is the search for efficient active medium for NPA.

To decide the first problem the energy model of a pulse nuclear reactor pumped laser system is created at IPPE [5]. Optical scheme of this model is analogous to that shown in fig.1. The electron beam pumped laser is used as master oscillator. Nuclear pumped amplifier (NPA) is basis of the model. Two core "Bars-6" [6] fast burst reactor with following parameters: dimensions of active cores - 220 x 220 mm; distance between cores - 1500 mm; the number of fission in two cores - $5 \cdot 10^{17}$ and the pulse duration - 40 μ s is used as ignition module (see the Fig.3).

Laser module is cylindrical structure with longitudinal cavity for location of two cores of reactor module (see the Fig.4). Diameter of laser module is 1700 mm, length - 2500 mm. Laser module consists of laser active elements (LAEL's), imitators of LAEL and neutron moderator elements. At the side laser module is surrounded by the two rows of the neutron reflector elements.

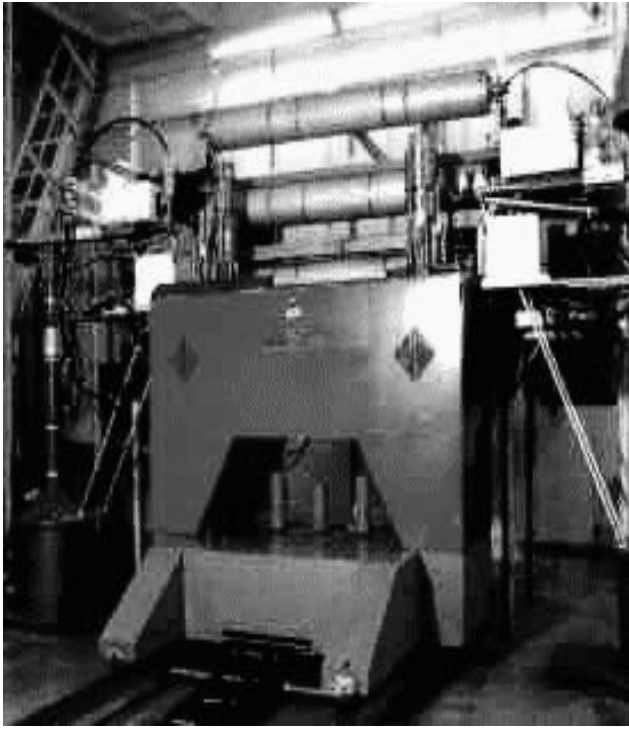


Fig.3. Fast burst reactor BARS-6.

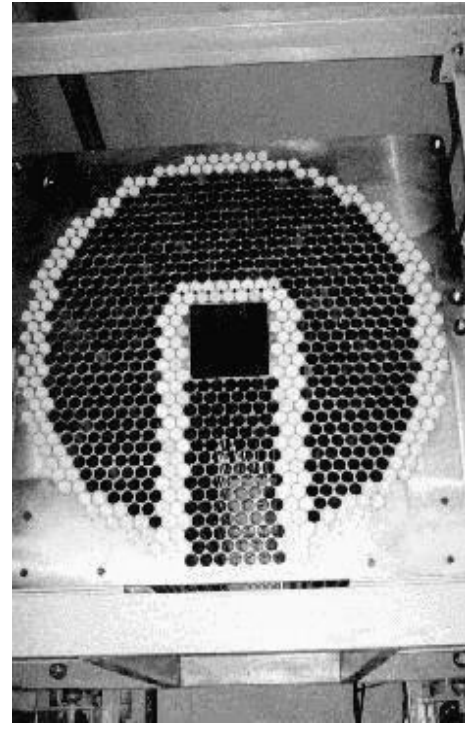


Fig.4. Laser module.

Conceptual designs of LAEL and its imitator are shown in fig.5. LAEL is a thin-wall stainless steel tube 50 mm in outer diameter and 2500 mm length with internal ~ 5 mm thickness metal uranium-235 coating and with optical windows filled with a laser active medium. Ar-Xe mixture (200:1) with approximately normal pressure is used as a laser active medium. This option is explained by the fact that this medium is most studied now and dealing with this is simply sufficiently. Imitator of LAEL concerning the neutron-physical aspect is copy of LAEL.

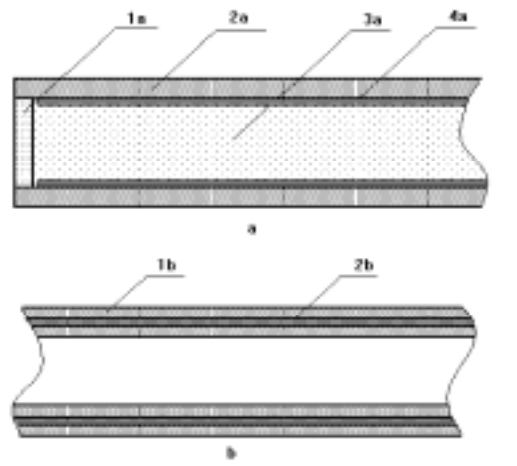


Fig.5 Conceptual designs of LAEL (a) and its imitator (b). 1a - optical window, 2a - stainless steel tube, 3a - laser active medium, 4a - metal uranium-235 coating, 1b - aluminum tubes, 2b - dioxide of uranium-235.

The NPA functions as follows. Traveling into laser module neutrons of the ignition reactor are moderated and induce a chain fission reaction of uranium-235 in the coating of LAEL (Fig.6). Stopping in Ar-Xe mixture fission fragments induce nuclear-induced plasmas in that with the inversion population of Xe1 levels corresponding to the laser transition with wavelength $1.73 \mu\text{m}$. The energy stored in the inversion population is extracted from laser module by the optical system of model.

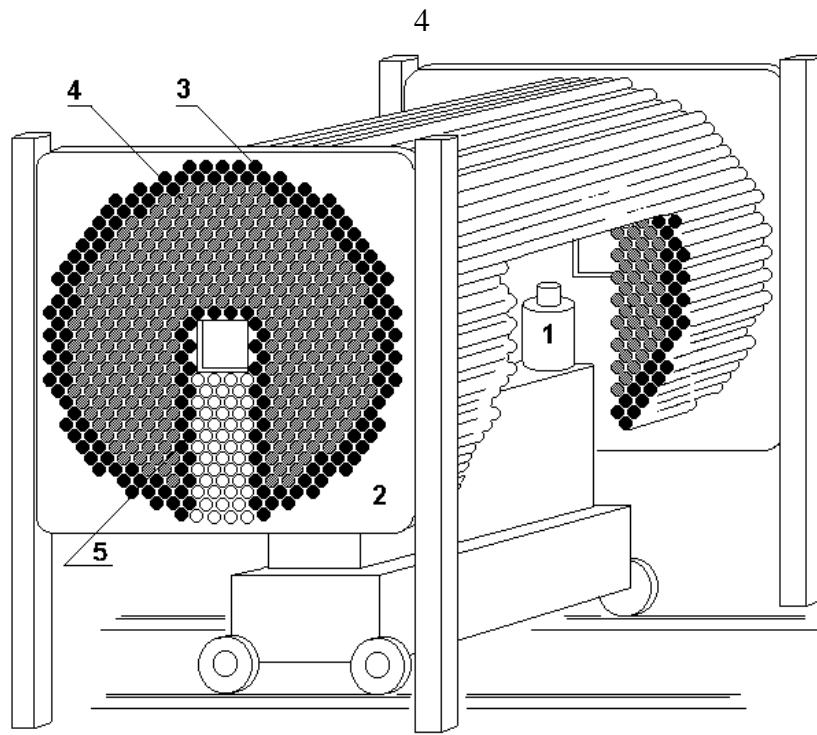


Fig.6. Scheme of energy model of a pulse nuclear reactor pumped laser. 1 - active core of burst reactor, 2 - laser module, 3 - neutron reflector, 4 - laser-active elements, 5 - imitators

Calculation performed in [5] showed that for total replacement of the imitators to LAEL's (~600 units) the energy of the model laser pulse can reach to 10-100kJ for the pumping pulse duration ~ 2 - 10 ms.

At the present time the state of activities on realization of the energy model is following: the setting into energy operation of the reactor module is achieved; the physical start-up of the reactor with laser module is finished; experimental research of the general components of laser module, optical system and diagnostic system of a laser beam is performed.

4. SOME OF THE EXPERIMENTAL RESULTS

To solve the second problem the investigations for searching the effective laser media for NPA are carrying on the reactor BARS-6 for gaseous and liquid media. As for the last ones some of the experimental results are discussed in [4, 9,10].

In the framework of designing an energy model of a pulse nuclear reactor pumped laser system in the IPPE [5], lasing experiments were performed on ^{235}U fission fragments pumping of 5d-6p atomic xenon 1.73 μm transition [7].

The objectives of experiments were to observe the laser oscillation and amplification effects, to evaluate a power parameters of laser and amplifier and to study the stability of metal uranium coating of laser active elements under pulse neutron and γ -irradiation.

The scheme of the NPL experiment is shown in Fig.7. The laser cell and quantum amplifier were placed into the cylindrical polyethylene neutron moderator block with external $\text{Ø}260 \times 2000$ mm and internal $\text{Ø}160$ mm covered by cadmium sheets. The laser cell is a thin walled stainless steel tube with outer diameter 49 mm and length 400 mm. From one side it was equipped with 6-m curvature concave gold high reflection spherical mirror and on the other side - with a quartz Brewster's window. A flat dielectric mirror with reflectivity 95% at 1.73 μm was used as an output coupler. A 300-mm-long aluminum cylinder coated with a ^{235}U dioxide layer of thickness 2.7 mg/cm^2 was placed into the laser cell. The laser active element was used as a quantum amplifier. Both sides of the LAEL were hermetically sealed with quartz optic windows having a dielectric antireflection coating for 1.73 μm . Both the laser cell and LAEL were filled with Ar+0.5%Xe gas mixture at 380 Torr pressure.

The optic scheme of experiment has two channels which were created by beamsplitter placed on the amplifier input. The transmission of beamsplitter was 0.32. The high reflection mirror with 10 m radius of curvature has been used for a two-round-trip amplifier scheme. In order to eliminate the uncertainty connected with the limitation of laser beam cross section in both channels, a restrictive 16-mm aperture was placed in front of the splitter plate. As determined computationally, for this case the cross section of the laser beam does not restrict along whole optical tract in both channels. The plate aluminum and spherical dielectric mirrors were used as turning ones. Tuning of optical system and

transmission measurements were carried out using a He-Ne laser. The measured transmission in the input channel was $6.3 \cdot 10^{-2}$, and $1.9 \cdot 10^{-2}$ in the output channel of the amplifier.

A thermocouple calorimeter and germanium photodiodes were used for registration of laser energy and time behavior of laser pulse.

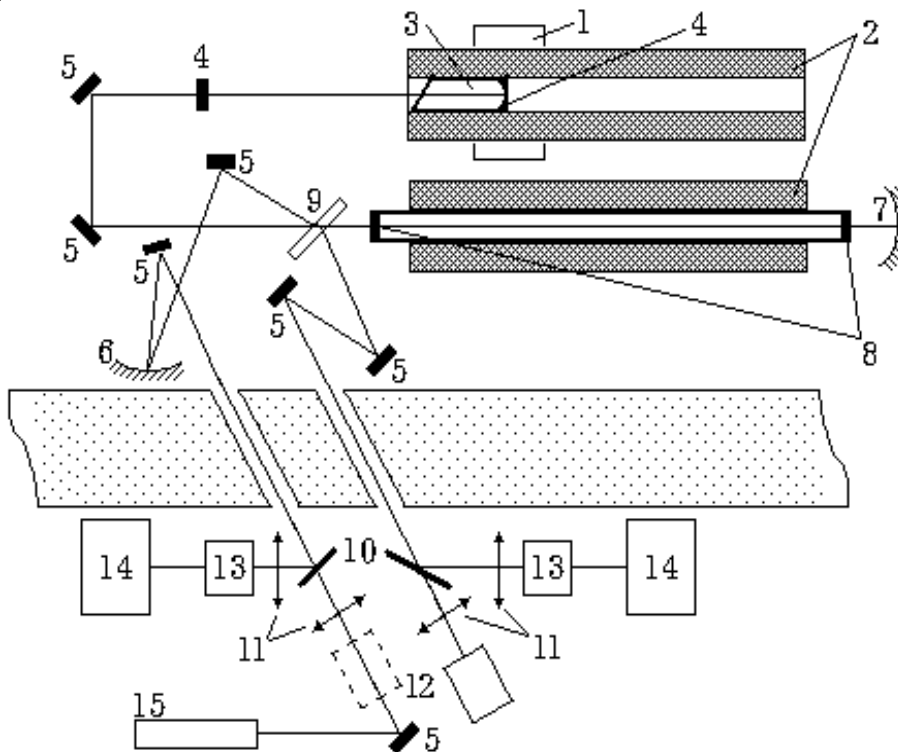


Fig.7. The experimental setup scheme: 1-cores, 2-moderator, 3-master oscillator cell, 4-cavity mirrors, 5, 6, 7-turning mirrors, 8-amplifier windows, 9, 10-beamsplitters, 11-lenses, 12-calorimeter, 13-photodiode, 14-digital oscillograph, 15-tuning laser.

Typical time-dependent $1.73\text{-}\mu\text{m}$ atomic xenon laser output in a free oscillation mode and thermal neutron signal are shown in Fig.8. The total laser oscillator output energy without restrictive aperture and beamsplitter was 200 mJ. The thermal neutron signal from the vacuum ^{235}U fission chamber has been normalized to the thermal neutron fluence measured by activation method. Laser output signal from Ge-photodiode has been normalized to total energy measured by calorimeter. The pump power has been evaluated from thermal neutron flux value and fission fragment energy deposition into the laser medium. The last value was obtained with Monte Carlo simulation of fission fragment stopping [8]. Input and output amplifier intensity are presented in Fig.9. The registration energy gain in amplifier was ~ 4 .

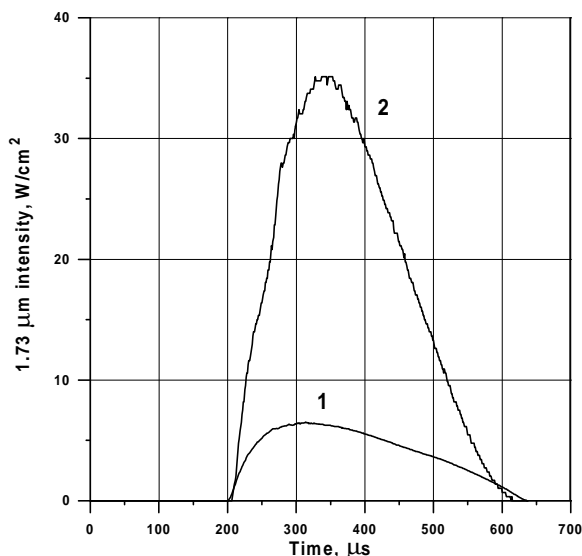


Fig.7. Neutron (1) and laser (2) pulses.

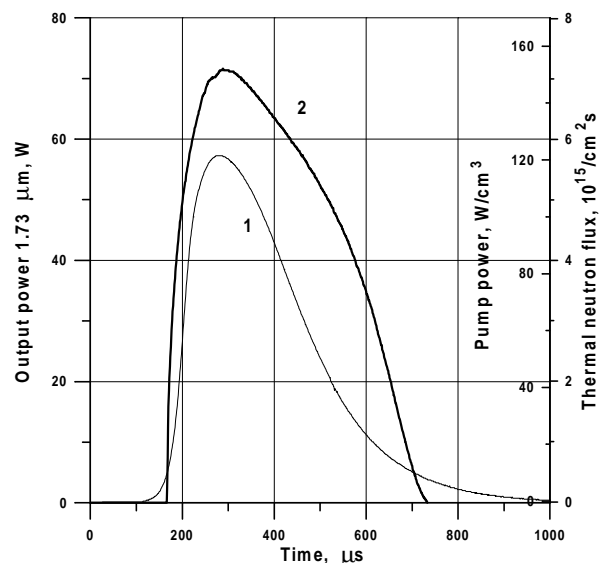


Fig.8. Input (1) and output (2) amplifier intensity.

5. CONCLUSION

Thus conception of a high-power periodically pulsed reactor-pumped laser system (RPLS) which could be used for the technology and other applications is described. The energy model of this system based on the fast burst reactor BARS-6 and subcritical laser module filled with an Ar-Xe laser active medium is under construction in Institute of Physics and Power Engineering (Obninsk, Russia). The optical scheme «master oscillator - quantum amplifier» was successfully tested in the experiments on BARS-6 reactor. The registration energy gain in amplifier (~4) was demonstrated.

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