1.7 A Optimized Design of Rectangle Pumping Cell for Nuclear Reactor Pumped Laser

J.-S. Wan L.-X. Chen Z.-M. Zhao X.-B. Pan C.-Y. Jing X.-Q. Zhao F.-H. Liu

(*Northwest Institute of Nuclear Technology, P. O. Box* 69-16(9), *Xi'an*, 710024, *China*)

Abstract: Basing on our research of energy deposition in RPL pumping cell and the laser power efficiency, a RPL test device on Pulsed Reactor has been designed. In addition, the laser beam power of the RPL test device is estimated in the paper.

Key words: Nuclear Reactor Pumped Laser, laser designation, energy deposition, laser power efficiency

1. Introduction

It has been demonstrated that the laser at wavelength 1.73 μm can reach an intrinsic efficiency varying from 1% to 4%[1-10], when rare gases containing Xenon are pumped by electrons or nuclear reaction products. It can be designed to be a new kind of high power laser facility. Moreover, it has a long working-life because its working medium of Xenon laser is inertial gases. Therefore much research has been carried out in this field.

Nuclear pumping is a kind of promising laser pumping technology. The main process is based on the capture of neutrons by the laser medium in nuclear reactor. When neutrons are captured by nuclei of laser medium gas atoms, these nuclei will fission or decay and energy is released. Particles carrying the energy produced during the nuclear reaction process interact with the laser gas, cause the particles number reversed, and laser is produced. Inasmuch as nuclear pumped laser has some attractive advantages, such as high-energy output as well as long working-life, some countries, e.g. USA and Russia, attach high importance to this technology. A Fast Neutron Pulsed Reactor (SPR-3) and a Circular Pulsed Reactor (ACPR) have been specially used for this research in Santia National Laboratories of USA.

Basing on our former studies, a rectangle pumping cell for nuclear pumped laser were studied in the following sections. The geometric parameters and gas composition will be optimized.

2. Theoretical and designing basics

The laser medium used in the study consists of ^{3}He-Ar-Xe. It belongs to volumetric pumping system. ^{3}He will interacts with neutrons in a neutron field. The reaction products fly into laser medium with the nuclear reaction energy. The laser medium obtains energy by collision with the products. It causes the particles number reversed, and 1.73 m laser can be produced.

In the volumetric pumping system of nuclear reactor laser, ^{3}He nuclides capture neutrons in a neutron field, and the following reaction occurs:

$$^3He + n \to ^1H + ^3H + 0.76MeV \qquad \ldots\ldots\ldots\ldots(1)$$

According to the energy balance and momentum balance, the energies carried by ^{1}H and ^{3}H can be calculated to be 570 keV and 190 keV, respectively. Then the energy deposition for special geometry (deposition in a film) can be calculated with TRIM-code.

The TRIM code[11] was designed by J.J.Ziegler in IBM Company using Monte Carlo method in order to simulate the ions deposition in a medium. It can treat the deposition problem, medium stopping power and medium ionization when the ions bombard at a fixed point and fly towards a fixed direction in the target. However, there is no geometrical treatment in this code, it cannot calculate the ions' transportation, the energy-deposition and -loss in the laser cavity of different geometry. So, the EDL was developed with Monte Carlo method to solve the geometrical problem in our group[3].

The irradiation chamber of the reactor was designed as (1287×500×500 mm^3). We will use this chamber as neutron field. Considering the neutron flux, the neutron uniformity and the laser gain, the cell will be designed as rectangle and many time reflecting chamber (300×300×60 mm^3). The laser will be guided out off the reactor by optical fiber. The laser set-up and cell are show in Fig.1 and 2.

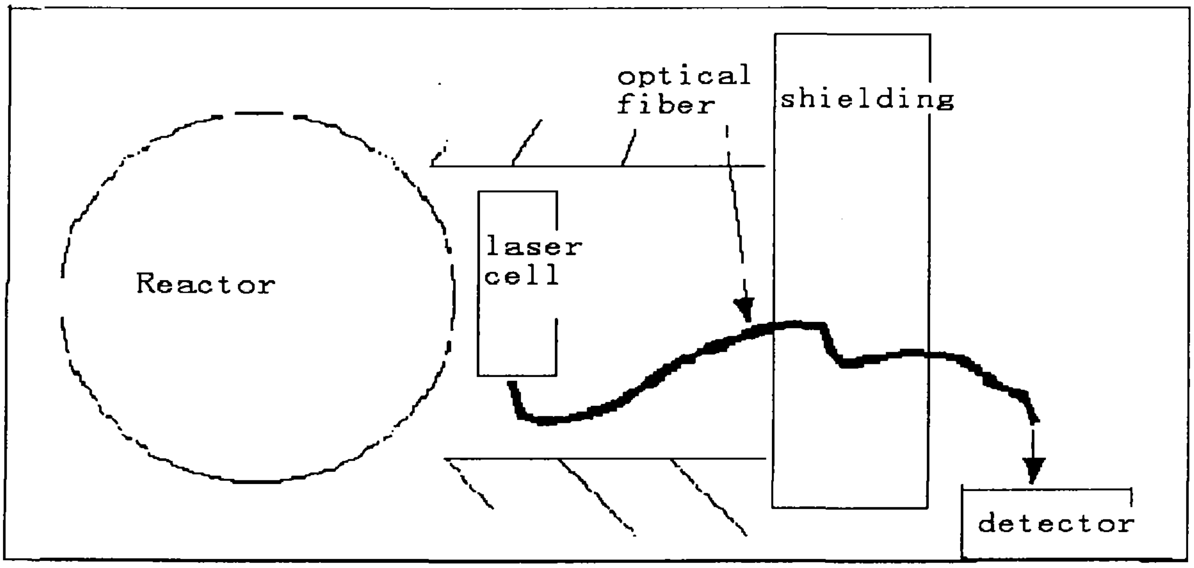

Fig.1 Scheme of nuclear pumped laser set-up

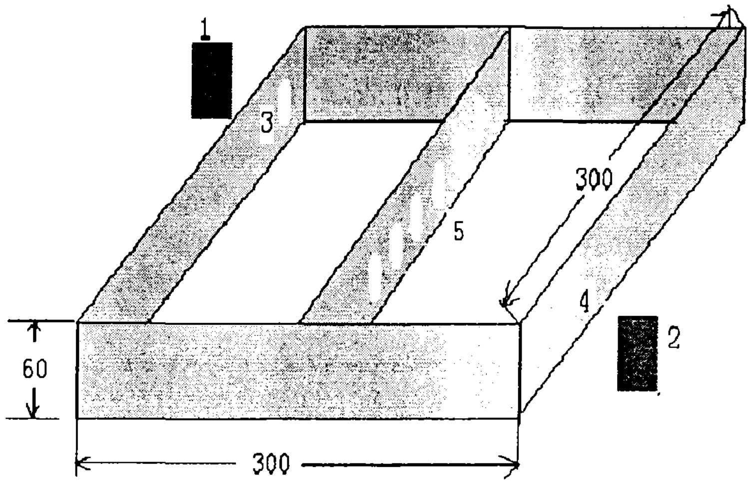

Fig.2 Laser cell. 1 and 2 are reflecting mirrors, 3 and 4 are transparent lens, 5 is diaphragm.

2. Design of pumping cell

In literature[12,13], the mechanism was proposed by our team, and the function of intrinsic efficiency was driven as follows:

$$\varepsilon_0 = \{1.438\times10^{-5}P^{He} + 4.342\times10^{-5}P^{Ar} - P\cdot(1.937\times10^{-10}P^{Ar} + 6.416\times10^{-11}P^{He})\}\times \{1.965 - 1.211(\log C^{Xe}) - 0.504(\log C^{Xe})^2\}(1.013 - 0.0138A + 0.00104A^2 - 0.000034A^3) \quad \ldots(2)$$

Note that P denotes the total pressure [Pa] of the system, while P^{He} for the partial pressure [Pa] of He atoms, P^{Ar} for the partial pressure [Pa] of Ar atoms, C^{Xe} for the Xe concentration (%) in the cell, A for the energy deposition density [W/cm^3].

Differentiating Eq.2 by $logC^{Xe}$, and let it equal zero, then:

$$C^{Xe} = 10^{-\frac{1.211}{1.008}} = 0.063(\%) \qquad \ldots\ldots\ldots(3)$$

From Eq.3, one can see, when the Xe concentration reach 0.063%, we can obtain a best efficiency.

In our former work[13], the relationship between the thickness of pumping cell and energy deposition efficiency was studied. A function of optimal thickness (mm) concerning ^{3}He partial pressure (Pa) was obtained as follows:

$$thickness = 139.2 - 3.02\times10^{-3}P^{He} + 2.45\times10^{-8}(P^{He})^2 - 6.75\times10^{-14}(P^{He})^3 \quad \ldots\ldots\ldots(4)$$

In the present study, the thickness of pumping cell is designed as 60 mm. So, the He partial pressure can be obtained as 3.5×10^4 Pa when one consider the above relationship.

According to Hebner's experiments[1], the gain can reach its maximum when the both partial pressure of He and Ar are the same. So, the Ar partial pressure can be taken as 3.5×10^4 Pa. All the parameters are listed in table 1.

Tab.1 Parameters of pumping cell.

length、width (mm)	Thickness (mm)	Total pressure (Pa)	He partial pressure (Pa)	Ar partial pressure (Pa)	Xe concentration (%)
300	60	7×10^4	3.5×10^4	3.5×10^4	0.063

3. Energy deposition in cell and laser power

According to the above gas composition, one can easily calculate the energy deposition efficiency in the cell and the neutron shielding effect of ^{3}He using EDL code. The results are given in figure 3. As the cell thickness increases, the energy deposition efficiency increases. But the ^{3}He number per cm^2 increases too. So, the neutron shielding effect of ^{3}He becomes stronger (the neutron utility decreases). Therefore, the total energy deposition efficiency (considering the neutron shielding effect) will not always increases, there should be a maximum total efficiency. According to the above parameters, the total efficiency appears when the cell thickness is 60 mm, where the total energy deposition efficiency is 57.5%.

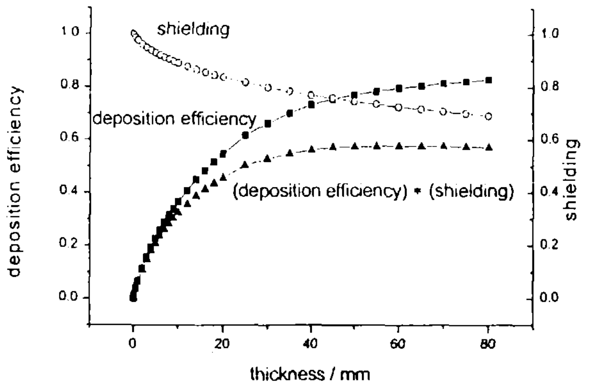

Fig. 3 Energy deposition efficiency and neutron shielding effect. (thickness=60mm, energy deposition efficiency=79.6%, neutron shielding effect=72.3%, total efficiency=57.5%)

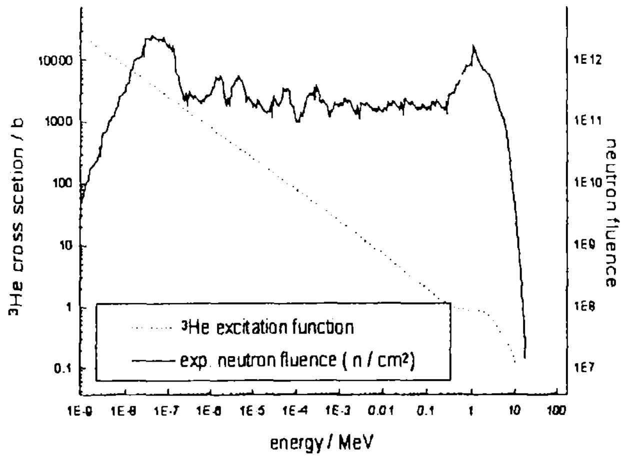

Fig.4 Neutron Spectrum and ^{3}He excitation function

If a reactor pulses at full power, and the neutron spectrum is given as shown in figure 4. The total neutron fluence is given as 2.1×10^{14} n/cm^2. The ^{3}He excitation function is also shown in the Fig.4. The average cross section is 2400 b.

In the literature[3], we have obtained the energy deposition density function concerning the ^{3}He partial pressure P^{He} (Pa), neutron flux ϕ (n/s/cm^2), reaction cross section σ (cm^2) and energy deposition efficiency β. That is:

$$A = 32.41\times P^{He}\times\sigma\times\phi\times\beta \qquad \text{............(5)}$$

The above equation can be principle used, but this function was driven using a 600 mm long cylinder chamber. In the present work, we use a many time reflecting chamber (rectangle). So, this function should be modified to be used in the present work. In the cylinder chamber, the optical path is only 600 mm in the cell. In the rectangle chamber, the laser light reflects 6 times in the cell, so, the optical path is about $300\times6=1800$ mm. Using Eq.2 and 5, one can calculate the laser power, it's about 137 J (the power loss on the reflect mirrors is presumed to be 30%).

4. Conclusion

The above design is only a principle one. Whether it is reasonable depends on experimental results. But it is a base for farther theoretical and experimental studies.

Literature

1. G.A.Hebner and G.N. Hays, J. Appl. Phys., 1993, 74, p3673.
2. J.-S.Wan, C.-Y.Jing, D.Chen, etal., Studies on Energy Deposition in the Nuclear Reactor Pumped ^{3}He-Ar-Xe Gas Laser Cavity, Proc. of 5Th China-Russia International Conference on Laser Physics and Application, P74, Russia, Oct. 2000.
3. J.-S. Wan, C.-Y. Jing, D. Chen, etal., Theoretical Studies on Power Deposition in the Nuclear Reactor Pumped ^{3}He-Ar-Xe Gas Laser Cavity, High Power Laser and Particles Beams, 13(4), 413-417(2001) (Chinese).
4. G.A.Hebner and G.N. Hays, J. Appl. Phys., 1993, 73, p3614.
5. M. Ohwa, T.J. Moratz, and M.J.Kushner, J.Appl. Phys. 1989, 66, p5131.
6. J. Alford and G.N. Hays, J. Appl. Phys. 1989, 65, p3760.

7. P.J.M. Peters, Q.-C. Mei and E.J. Witteman, Appl. Phys. Lett. 1989, 54, p193.
8. W.T. Silvast, L.H. Szeto and O.R. Wood II, Appl. Phys. Lett., 1977, 31, p223.
9. S.A. Lawton, J.B. Richards, L.A. Newman, L. Specht and T.A. DeTemple, J. Appl. Phys. 1979, 50, p3888.
10. Thormas E. Repetti, Application of Reactor-Pumped Lasers to Power Beaming, Idaho National Engineering Laboratory, Information Report, EGG-PHY-9978, Oct.1999.
11. J. P. Biersack and L. Haggmark, Nucl. Instr. And Meth., 174, 257(1980).
12. J.-S. Wan, C.-Y. Jing, D. Chen, etal., Studies on the Power Efficiency for the He-Ar-Xe System of Nuclear Reactor Pumped Laser, High Power Laser and Particles Beams, 13(6), 562-567(2001) (Chinese).
13. J.-S. Wan, C.-Y. Jing, D. Chen, etal., Studies on the Mechanism of the Nuclear Reactor Pumped Laser for ^{3}He-Ar-Xe System, accepted to publish in 'Chinese Journal of lasers'(Chinese), Accept No.1-25.
14. JEF-PC Nuclear Data Bank, 1985.