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The progress of nuclear pumped laser in CFBR-II reactor

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Development of nuclear pumped lasers (NPL) in the CFBR-II reactor is briefly reviewed. The results of the two NPL experiments in CFBR-II reactor are described. The first one focused on the principle of nuclear pumped laser, and 4-mW laser output power achieved. The second NPL experiment focused on the small signal gain and the efficiency of the nuclear pumped He-Ar-Xe gas mixture at 1.73 μm. The maximum laser power measured to be 45 mW when thermal neutron flux rate is 6.9×10^{14} cm$^{-2} \cdot$ s^{-1}. The small signal gain at 1.73 μm by the Rigrod analysis method is to be 0.24%·cm^{-1}, and the saturation intensity is fitted to be 36 W/cm^2.

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Atom xenon laser operates on several infrared transitions (1.73 – 3.5 μm) between the $5d - 6p$ levels. It has reported that intrinsic nuclear pumped laser power efficiencies of atom xenon laser exceeded 5%[1] at 1.73 μm ($5d[3/2]_1 - 6p[5/2]_2$). The ^{235}U (n,f), ^{3}He (n,p)T, and ^{10}B $(n,\alpha)^7$Li reactions are often used to excite xenon atom, the energy released from these reactions are about 180, 2.3, and 0.76 MeV per reaction respectively[1]. It has been demonstrated that the 1.73-μm laser pumped by nuclear energy has a high intrinsic efficiency, as well as some other advantages, such as relative low pumped threshold (thermal neutron flux rate less than 10^{12} cm$^{-2}\cdot$s^{-1}) and can work at intense radiation *et al.*; a majority of such work on the atomic xenon laser has focused on this transition in many laboratories. The ^{3}He (n,p) reaction is often used to excite ^{3}He-Ar-Xe gas mixture in many such studies. And so do the studies in the CFBR-II (China Fast Burst Reactor – the Second) reactor.

$$^3\text{He} + n \rightarrow \text{T} + p + 0.76\ \text{MeV}. \qquad (1)$$

The energy release from the reaction excite the atom Xe from $5d$ energy level to $6p$ energy level.

There are three pulse- or burst-reactors in China, two are TRIGA type, and the other is GODIVA type, i.e. CFBR-II reactor operated by CAEP. It is a fast burst reactor, which can offer a fast neutron flux rate of 10^{16} cm$^{-2} \cdot$ s^{-1} at the outer of the reactor at the burst mode of normal yield.

The first lasing experiment of nuclear-pumped laser in CAEP was carried out in 1994; it focused on the principle of nuclear pumped laser. CFBR-II reactor operated in burst mode was used as a burst thermal neutron source. In that experiment He-Ar-Xe mixture gas as laser medium was excited by ^{3}He (n,p)T reaction energy. The laser medium was put at the outer of the CFBR-II reactor. The schematic diagram of experiment is shown in Fig. 1. When the thermal neutron flux in the lasing cell is 6.9×10^{14} cm$^{-2}\cdot$s^{-1}, the observed wavelength was 1.73 μm measured by glass filters, and the laser power of about 4 mW was achieved[2].

The second experiment to measure small signal gain and efficiency of reactor-pumped He-Ar-Xe laser at 1.73 μm was carried out in 1997. The schematic diagram of the second experiment is the same as the constructions of the first NPL experiment. The only difference is the ratio of the mixture gas.

A 135(OD) × 50(ID) × 720(L) mm^3 high-density polythene sleeve is put at the side of CFBR-II reactor as neutron moderator. A group of Au foils are used to measure the neutron flux distribution in the moderator. At the expected burst yield, the fast neutron flux in the center of the lasing cell is 7.0×10^{15} cm$^{-2}\cdot$s^{-1} without the moderator, and the thermal neutron flux at the same point is 6.9×10^{14} cm$^{-2} \cdot$ s^{-1} with moderator. The thermal neutron pulse width in the laser cell is 735 ms, while the fast neutron pulse width is 194 ms. Through 42.5-mm-thick polythene sleeve, the fast neutron is moderated to thermal neutron, its pulse width is broaden and the intensity decreases. The glass laser cell, which is $\Phi 34 \times 600$ mm^2 in dimension, is put into the moderator sleeve; two quartz Brewster's windows are located at both end of it. Two 900-mm-long resonant cavity mirrors are put on the two ends of the moderator axis. A fiber is used to transit the laser beam and the fluorescence of laser gas medium from the reactor hall. A Ge semi-conductor detector and an oscilloscope are used to detect and record the laser signal respectively. The narrow band cavity mirror is used to suppress Xenon atom 2.03 μm wave transition. The purities of ^{3}He, Ar and Xe gas analyzed by chemical method exceed 99.99%, respectively; the ratio of the mixture gas fractional pressure is 80.2 : 19.3 : 0.5 for ^{3}He/Ar/Xe; the

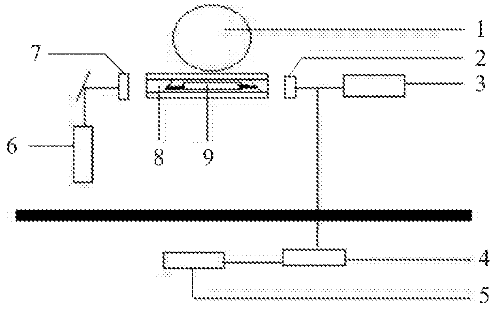

Fig. 1. Schematic diagram of the experiment configuration. 1: CFBR-II reactor; 2: outcoupler; 3: innerfocus; 4: Ge detector; 5: oscilloscope; 6: He-Ne laser; 7: reflector; 8: polythene moderator; 9: lasing cell.

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total pressure of the mixture gas is 8.92×10^4 Pa.

Six mirrors with the transmission (T) from 1.7% to 10% were used. The laser power, the FWHM of the laser signal and the neutron flux of each mirror have been measured. The laser power for six mirrors are showed in Fig. 2 and Table 1. The output power of laser can be expressed by Rigrod theory as

$$P_l = \frac{I_s A t_2 \sqrt{r_1}\left[(g_0 - \alpha_0)L + \ln\sqrt{r_1 r_2}\right]}{(\sqrt{r_1} + \sqrt{r_2})(1 - \sqrt{r_1 r_2})(1 - \alpha_0 L/\ln\sqrt{r_1 r_2})}, \quad (2)$$

where P_l is laser power; g_0 is small signal gain; I_s is saturation intensity; α_0 is the non-saturate distributed loss per unit length, it is small, about zero; r_1 and r_2 are effect reflections of two coupler mirrors respectively, $r_1 > 99.9\%$; t_2 is effect transmission of the output mirror; L is the length of laser cell, equals 0.9 m; A is the dimension of the laser beam, $A = (\lambda L/\pi)^{1/2}$.

$$\begin{aligned} r_2 &= (1 - T)(1 - 0.5\%)^2, \\ t_2 &= T(1 - 0.5\%), \end{aligned} \quad (3)$$

where the values of T are listed in Table 1.

From Eq. (2), the small signal gain and the saturated intensity of the laser can be fitted. The small signal gain is fitted as $0.24\%\cdot\text{cm}^{-1}$ (±22%), while the saturation intensity of the laser is $36\ \text{W/cm}^2$ (±40%). From the output laser power vs different transmission rate of out couplers curve, it also can be concluded that, in order to get the maximum output laser power, the transmission rate may be 5.6%. The pumped efficiency can be shown by

$$\eta = \frac{P_l}{P_{\text{dep}}}, \quad (4)$$

where P_l is the output laser power and P_{dep} is the power depositing in the gas, which is in proportion to neutron flux rate, number of ^{3}He atom, and thermal neutron cross section. The maximum power got in our experiment is 45 mW as the out coupler transmission rate to be 7%. The depositing power in the cavity can be calculated from the following equation by integrating all the correct factors to one.

$$P_{\text{dep}} = 1.0 \times 10^{-19} p_{\text{He}} \phi, \quad (5)$$

where ϕ is the neutron flux rate; p_{He} is the pressure of He in Pa.

Then the efficiency is calculated to be 1% in conclusion, increasing to be about 10 times of that of the first experiment.

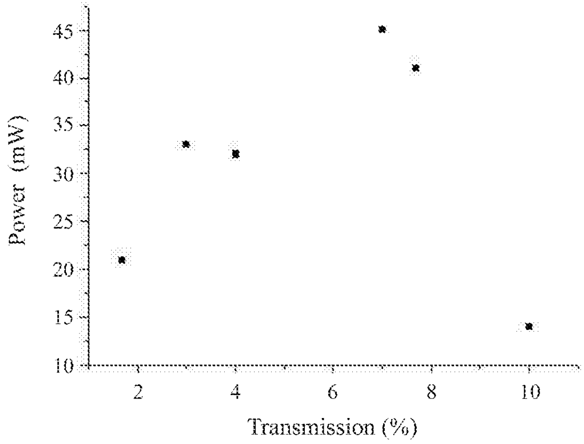

Fig. 2. Laser power vs output coupler transmission.

Table 1. The Laser Power and the Output Coupler Transmission

T (%)	Laser Power (mW)	FWHM of Laser Signal (μs)
1.7	21	320
3	33	300
4	32	300
7	45	320
7.7	41	320
10	14	320

The maximum laser power of nuclear pumped He-Ar-Xe mixture gas in CFBR-II reactor measured to be 45 mW when thermal neutron flux rate is 6.9×10^{14} c $\text{m}^{-2}\cdot\text{s}^{-1}$. The small signal gain at 1.73 μm by the Rigrod analysis method is fitted to be $0.24\%\cdot\text{cm}^{-1}$, and the saturation intensity is fitted to be $36\ \text{W/cm}^2$. The fast burst reactor can be used as neutron source to carry out the nuclear pumped laser test. In the experiment, it is also showed that the pumping power from He (n,p) reaction is relatively low, and the distribution of pumping power in the laser cell is not heterogeneous, so the laser power is very small. To increase the output power of laser, the ^{235}U (n,f) and ^{10}B (n,α) reactions may be used.

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