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The development of a joule level of XeF(C-A) laser by optical pumping

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Abstract

A joule level of XeF(C-A) laser optically pumped by a sectioned surface discharge was developed. The irradiative intensity of pumping source was diagnosed by calculating XeF_2 photo-dissociation wave evolvement which was photographed by a framing camera. The photon flux in the wavelength region of 140 to 170nm is about 5×10^{23} photon $s^{-1}cm^{-2}$, that corresponds to the irradiative brightness temperature of more than 25000 K. The laser experiments were carried out in different conditions. The maximum laser output energy of 2.5 J was obtained with the total conversion efficiency of 0.1%.

Keywords: Optical pumping; Photo-dissociation; XeF(C-A) laser

1. INTRODUCTION

The femtosecond lasers was applied widely in many scientific fields (Limpouch *et al*., 2004; Gavrilov *et al*., 2004; Lan *et al*., 2004) during the last decade such as fast ions generation (Magunov *et al*., 2003), fabrication of debris-free microstructure, surface processing of materials (Lenzer *et al*., 1998; Bernardo *et al*., 2003), thin film deposition (Yao *et al*., 1999) and strong field physics etc. . For the high intensity femtosecond laser system, the chirped-pulse amplification (CPA) technology is usually used, which involves employment of complex and costly optics systems. A new method of direct amplification of femtosecond laser pulses in photo-chemically driven XeF(C-A) laser was developed (Mikheev, 1992; Malinovskii *et al*., 2001; Mikheev *et al*., 2004; Tcheremiskine *et al*., 2002).

XeF(C-A) laser has several attractive characteristics: (1) blue-green irradiative spectra region from 450 nm to 520 nm with the center wavelength of 480 nm, which coincidences with the second harmonic of the Ti: sapphire laser. (2) Higher saturation energy density of 50 mJ/cm^2 compared with other excimer lasers. (3) Broad gain bandwidth (~70 nm) which makes it possible to amplify ultrashort pulses down to 10 fs. With above properties, XeF(C-A) laser has perspective applications for ultrashort laser amplification and other fields.

Several kinds of optical pumping XeF(C-A) lasers was developed in different laboratories. Zuev *et al*. (1992) obtained XeF(C-A) lasers with output energy of 117 J by surface discharge pumping with the total stored energy of about 90 kJ. Mikheev *et al*. (1995) developed a photo-dissociation XeF(C-A) laser with the output energy of 14.5 J pumped by exploding wire excitation. Sentis *et al*. (1997) developed a XeF(C-A) laser pumped by formed-ferrite open discharge radiation, in which the output energy of 1.3J was obtained. Kaecht *et al*. (2003) developed a compact surface discharge system with the stored energy of 5k J for optical pumping, a single pulse energy >50 mJ from XeF(C-A) laser and >0.7 J of atomic iodine laser were obtained. The conversion efficiency with respect to the energy stored in the capacitors for most of the laser devices mentioned above were less than 0.1%, but the best efficiency of 0.17% up to now was obtained by Zuev *et al*. (1992).

We began the research work with XeF(C-A) laser in 1995 and several papers were published (Hu *et al*., 2001; Yu *et al*., 1998, 2001). We have been trying to develop the sectioned surface discharge pumping source because of the ability of its higher total conversion efficiency and the capability of repetitively operation. At present, the maximum output laser energy of 2.5 J with the total conversion efficiency of 0.1% was obtained. In this paper, the XeF(C-A) laser device and the experimental results are described in detail.

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2. XeF(C-A) LASER DEVICE

The picture of XeF(C-A) laser is shown in Figure 1. The rectangular laser chamber is made of alnico with length of 116 cm and volume of about 10 liters. In order to decrease the intracavity losses, Brewster windows with aperture of $4.6 \times 5\ \mathrm{cm}^2$ are used. Lasing is investigated by employing a stable resonator with the length of 152 cm. In the experiments, flat output mirrors with the output coupling of 4% and 8% in the spectral range of 450 to 510 nm are used, respectively. The reflectivity of spherical mirror of 5 m radius is better than 99.5%. In order to restrict the lasing on the B-X transition of XeF, the reflectivity of each mirror in 351 ± 5 nm is below 10%. Laser chamber could be evacuated to below 5 Pa. The initial concentration of XeF_2 was determined by measuring the radiation absorption from a mercury lamp.

A Teflon substrate is placed on a sidewall of the laser chamber as the discharge base of pumping source. The electrodes for the primary discharge are fixed on the surface of the Teflon. The schematic diagram of the pumping source is shown in Figure 2. The irradiation from a signal-channel sectioned surface discharge with the effective gain length of 80 cm is used to photolysis XeF_2.The whole pumping source was divided by eight sections along the optical axis of the laser cavity. Each section consists of a pair of electrodes and one capacitor of 1 μF with the working voltage of 15 to 35 kV. The trigger electrode supplied high pulse of 25 kV is embedded in the Teflon substrate under main electrodes.

3. THE DIAGNOSTICS OF PUMPING SOURCE PERFORMANCE

The discharge current in each section was measured by a Rogowski loop. The typical oscillogram of a current is shown in Figure 3 (waveform 1). In the case of the charging voltage of 25 kV, the peak value of the current is calculated to be about 32 kA and the rising rate of it is $2.9 \times 10^9\ \mathrm{A\,s^{-1}}$. The equivalent inductance and resistance of the circuit are about 330 nH and 240 mΩ, respectively. The input average power per unit length of discharge plasma is 12 MW cm^{-1} during the first-half-cycle of the discharge and the deposited efficiency is 74%. The synchronization of the discharge of each section is very important for lasing. The jitter time of all discharge currents is measured to be smaller than 60 ns.

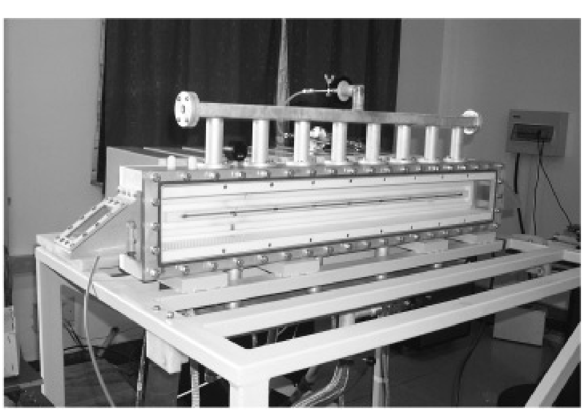

Fig. 1. XeF(C-A) laser device.

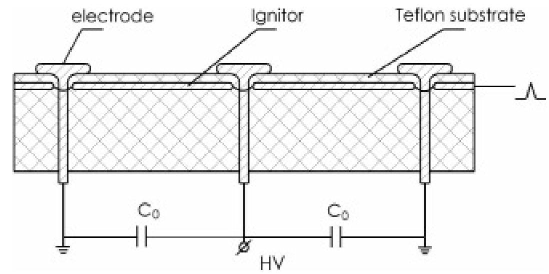

Fig. 2. Schematic diagram of the pump.

The irradiative intensity of pumping source was diagnosed by calculating the time evolution of XeF_2 photo-dissociation wave which was photographed by framing camera. Shown in Figure 4 are four frames of photolysis wave patterns recorded in the case of the initial XeF_2 concentration of $1.57 \times 10^{17}\ \mathrm{cm}^{-3}$ and the charging voltage of 30 kV. The exposed time of each frame is 5 ns and apart of them are 160 ns. The interval between first frame and the beginning of the discharge current is 530 ns. The XeF_2 photo-dissociation waves indicate the temporal and spatial change of the XeF(C-A) fluorescence layer. The velocity of the photolysis wave, as well as the thickness and the lifetime of fluorescence layer can be calculated from these patterns. We observed that the photo-dissociation wave with the thickness of 6 to 8 mm moved 3cm away from the Teflon surface in 2.2 μs.

The results of calculation show that the velocity of the photo-dissociation wave decreases with time. The maximum speed exceeds 25 km s^{-1} at the beginning of the discharge and the average velocity exceeds 10 km s^{-1} during the first-half-cycle of the current. The effective life-

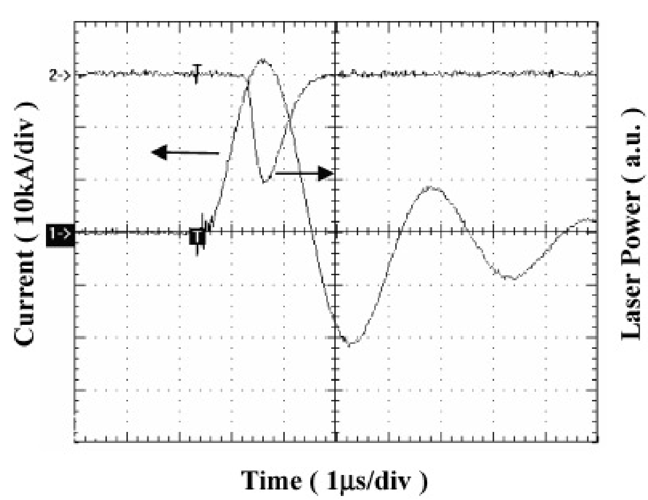

Fig. 3. Discharge current and Laser waveforms.

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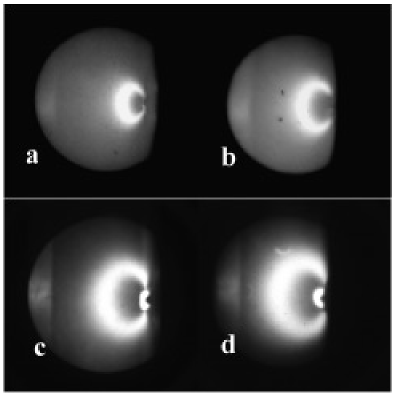

Fig. 4. Photographs of XeF_2 photo-dissociation.

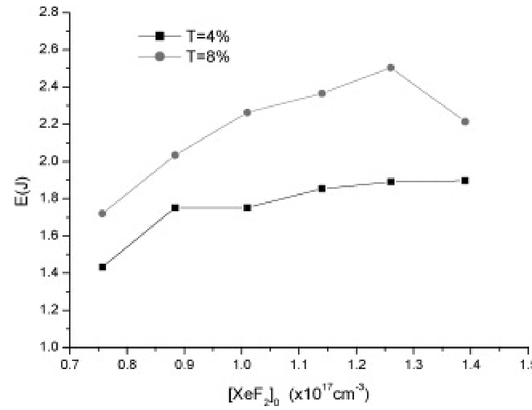

Fig. 5. Output energy vs XeF concentration at different output coupling.

time of the excited layer is 700 ns under such a fast evolved of the photo-dissociation wave, which is shorter than 1.2 to 2 μs described in Zuev *et al*. (1992) and Sentis *et al*. (1997). The value of the XeF_2 photo-dissociation rate W and the photon flux Φ into the absorption band (140 to 170 nm) of XeF_2 can be determined by the following equations (Sentis *et al*., 1997; Zuev & Mikheev, 1991).

$$W = N_0/\tau_{eff} \quad (1)$$

$$\Phi(t) = R(t)/r(t) \times V_{pdw}(t) \times N_0, \quad (2)$$

where N_0 is the initial XeF_2 concentration, τ_{eff} is the effective lifetime of an excited layer, $R(t)$ is the radius of the photo-dissociation wave, $r(t)$ is the discharge plasma radius and $V_{phd}(t)$ is the velocity of the photo-dissociation wave. The photo-dissociation rate and the average irradiative intensity in the 140 to 170 nm spectra are 2.2×10^{23} actors $s^{-1}cm^{-3}$ and 5×10^{23} photon $s^{-1}cm^{-2}$, respectively, which correspond to the value of brightness temperature up to 25kK.

4. THE EXPERIMENTAL RESULTS

The laser experiments was carried out in the case of $Ar:N_2 = 3:2$ at the total pressure of 100 kPa and XeF_2 initial concentration ranging from 0.76×10^{17} to $1.4 \times 10^{17} cm^{-3}$. The laser output energy was measured with $J_{max}43$ calorimeter. The laser pulse duration was detected by GD51Q photodiode and a typical laser pulse was shown in Figure 3 (waveform 2). A ULTIMA1024 camera with the speed of 2000 f/s was used to photograph the near-field laser beam pattern. The size of the laser beam is 2.7 cm $\times$ 3.6 cm. The spectrum of XeF(C-A) laser was recorded by a quartz spectrometer to be in the range of 470 to 495 nm.

The effect of the output coupling of laser cavity to the output energy was studied. The distance between the optical axis of laser and the surface of pumping source is 13 mm. The experimental results are shown in Figure 5. In the case of output coupling of 4%, the maximum output energy of 1.89 J with 700 ns pulse duration (FWHM) was extracted with a gas composition of $XeF_2:N_2:Ar = 1.26 \times 10^{17}$: 1.0×10^{19}: 1.5×10^{19}. The maximum output energy of 2.5 J was obtained with output coupling of 8% under the same composed gas and the total conversion efficiency is up to 0.1%. It is obvious that the output energies with transmissivity of 8% are higher than those in the case of 4% in the case of the initial XeF_2 concentration from 0.76×10^{17} cm^{-3} to 1.4×10^{17} cm^{-3}, which seems that the gain coefficient is higher than expected.

5. CONCLUSION

A joule level of XeF(C-A) laser optically pumped by a sectioned surface discharge was developed successfully. The rectangular laser chamber is made of alnico with length of 116 cm and volume of about 10 liters. The effective gain length of the laser is 80 cm and a plane-spherical stable resonator is used. The whole pumping source is divided by eight sections and each section consists of a pair of electrodes and one capacitor of 1 μF with the working voltage of 15 to 35 kV. The irradiative intensity of pumping source was diagnosed by calculating XeF_2 photo-dissociation wave evolvement which was photographed by framing camera. The photon flux in the wavelength of 140 to 170 nm is about 5×10^{23} photon $s^{-1}cm^{-2}$, which corresponds to the irradiative brightness temperature of more than 25000 K.

The maximum output energy of 2.5 J was obtained with the output coupling of 8% and the gas composition of $XeF_2:N_2:Ar = 1.26 \times 10^{17}$: 1.0×10^{19}: 1.5×10^{19}. The maximum total conversion efficiency is up to 0.1%.

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