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A Picosecond CuBr Laser

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Abstract. A novel method for the pulse shortening of the 578 nm spectral line from a CuBr laser is proposed in this paper. By amplifying a seeded picosecond dye laser through the active medium of a CuBr laser, nearly Fourier-transform-limited picosecond pulses of the CuBr laser have been obtained and the output characteristics are also investigated in detail.

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The CuBr laser, characterized by high repetition rate, high average power, output in the visible spectral region etc., has good potential for research and applications in many fields [1–3]. So far, investigations on the pulse shortening of CuBr lasers have been few, especially for the picosecond pulse CuBr laser which has never been reported. The reasons may be the following: The CuBr laser is a so-called self-terminated laser, of which the pulse duration is about 20–60 ns. Traditional mode-locking techniques have failed to produce 100% modulated pulse trains or subnanosecond pulses, because the typical gain duration of the CuBr laser represents only a few cavity round trips. This short build-up time, combined with a moderate modulation index, results in incomplete mode-locking. In Fig. 1, we have demonstrated two pulse forms by using active mode-locking. Under normal operational conditions, the modulation depth cannot exceed 50% as shown in Fig. 1a. Only when the CuBr laser was operated near threshold, could modulated pulse trains with a pulsewidth of the order of nanoseconds be produced as shown in Fig. 1b. However, the short pulse trains are not suited for practical uses because the output is usually very weak as well as unstable.

Using the idea that the build-up of laser oscillation is fast in a low Q value resonator, in 1974 Liberman and his colleagues obtained short pulses with a pulsewidth of 2.6 ns from a short cavity CuBr laser whose discharge region was 5 cm long and 5 mm in diameter [4]. Afterwards, short pulses with a pulsewidth of 4.5 ns from a CuBr laser whose corresponding dimensions were 22 cm and 2 cm were obtained in a similar way [5]. These authors used a CuBr laser tube as short as possible to generate short pulses.

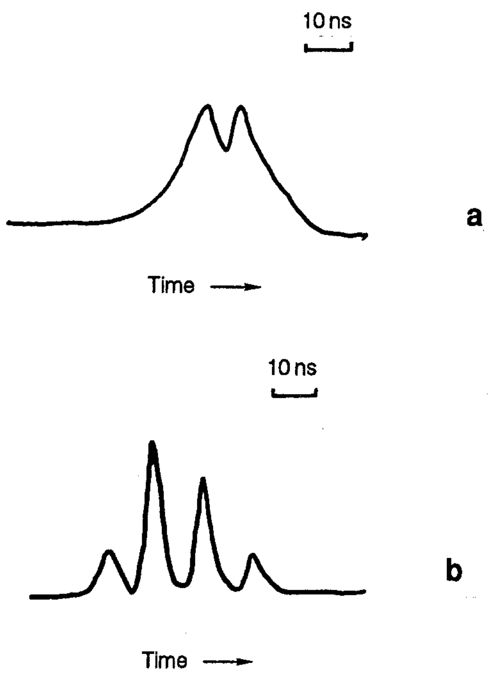

Fig. 1. a Oscilloscope trace of modulated pulse of CuBr laser. **b** Oscilloscope trace of active mode-locking pulse trains of CuBr laser near threshold

However, one cannot expect the CuBr laser tube to be shortened indefinitely, due to the rapid decrease in output power and the contamination of the quartz windows.

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The idea presented in this paper is based on the fact that a seeded ultrashort dye laser pumped by the 511 nm output from a CuBr laser could be produced, containing another spectral line of 578 nm. The dye laser was then amplified by passing the beam through the active medium of the same CuBr laser due to the inverted population of the 578 nm line. Nearly Fourier-transform-limited picosecond pulses of 578 nm were obtained from the CuBr laser and the output characteristics were also investigated in detail.

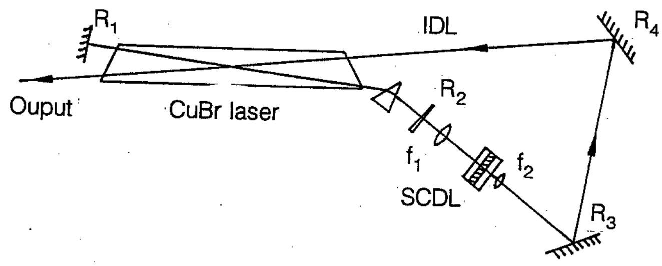

Fig. 2. Schematic diagram of the experiment

Experiment

The experimental set-up is schematically in shown Fig. 2. A home-made CuBr laser with a pulse duration of 25 ns and repetition rate from 10 kHz to 20 kHz was employed. The active zone of the CuBr laser was 50 cm long and the laser beam was restricted by quartz apertures to a diameter of 2 cm. The discharge tube was filled with neon buffer gas at a pressure of 15 Torr and, in most experiments, hydrogen was added at a pressure of 0.3 Torr. The discharge tube was self-heated and excited by a thyratron pulse generator. The resonator cavity consisted of a plane aluminium coated mirror R_1 and a flat quartz plate R_2. Unlike a normally operating CuBr laser, the resonator is tilted somewhat relative to the tube axis so that the other part of the active zone is left for the ultrashort dye laser beam to be amplified by its passage through the active medium of the same CuBr laser. All of the surfaces in the optical path were carefully positioned to avoid any harmful reflection, diffraction or parasitic oscillation. The output power of the CuBr laser was first attenuated by a series of calibrated neutral attenuators and then used to pump a short cavity dye laser (SCDL). Picosecond dye laser pulses could be generated by mixing a certain amount of saturable absorber in the SCDL. These pulses were described in detail in our previous work [6]. The diameter of the output beam from the SCDl was about 4 mm and it was led to the CuBr laser tube by mirrors R_3 and R_4. Under ordinary conditions, the build-up time of the 578 nm line for laser oscillations is delayed about 10 ns compared with that of the 511 nm line. This means that first the output of 511 nm was emitted to pump the SCDL and, at the same time, population inversion of the 578 nm line was being accumulated. After appropriate delays, the picosecond dye laser pulse was led to the same CuBr laser gain medium, and stimulated emissions at 578 nm were observed under optimum operation. It can be seen from following analyses that this output is nearly a Fourier-transform-limited pulse of the 578 nm.

Thermocouples were used to measure the temperature of the laser tube containing the copper bromide vapor. The temperature was measured on the outer wall of the quartz tube and it is this value which is given in the text. The temperature on the inner surface can be estimated if the magnitude of the dissipated power is known [7]. The dependence of the output power of the 578 and 511 nm lines on temperature is different and is indicated in Fig. 3. With this oblique axis geometry for the optical resonator, the output power of the CuBr laser decreased greatly since the active zone was diminished. The curves in Fig. 3 display the gain of both lines as a function of the temperature of the laser tube. It is evident that the gain of both lines increases with temperature. But they show somewhat different behavior. When the temperature was greater than 380° C, the discharge path would be curved and so unstable that is was not fit for amplification. We would thus ideally like the CuBr laser to be operated at 380° C in the experiment. The amplified output power was measured versus average power of the injected dye laser (IDL) at different temperatures of the CuBr laser tube as shown in Fig. 4. It is obvious that the output was weak and increased very slowly at low temperatures of 320° C. The output was relatively intense

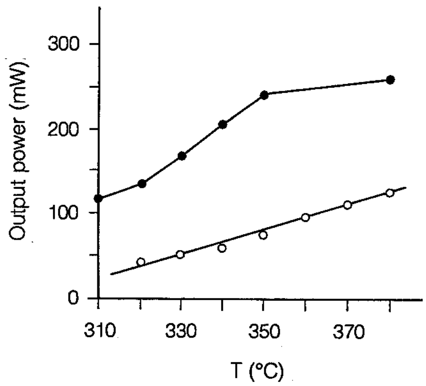

Fig. 3. The dependence of output power on the temperature of the laser tube. •— Green light (511 nm); ○— yellow light (578 nm)

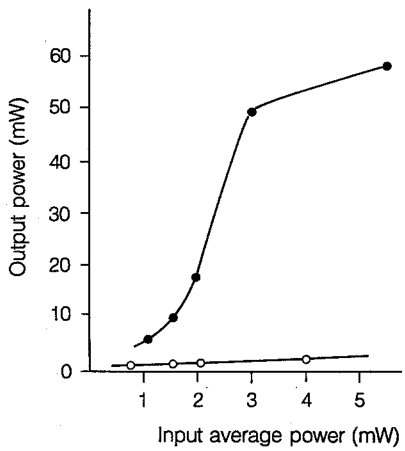

Fig. 4. Amplified output power versus input power. •— At a temperature of 380° C; ○— at a temperature of 320° C

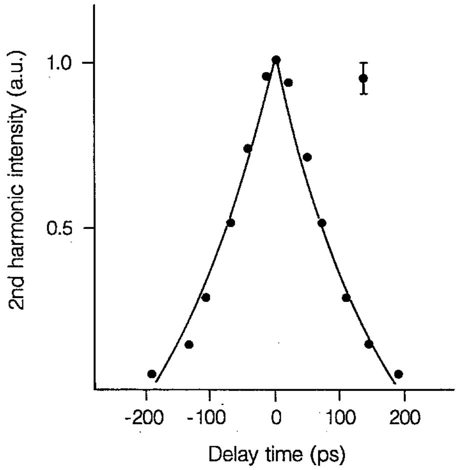

Fig. 5. Autocorrelation curve of the amplified 578 nm spectral line from the CuBr laser ($P_{out} = 50\,mW$)

and increased rapidly at a high temperature of 380° C. This also implies that to obtain higher output, the IDL power should be greater. Because the pulsewidth of the IDL from the SCDL was related to its output intensity as described in [6], it is impossible to obtain both higher output power and narrower pulsewidth of the dye laser simultaneously. The amplified output power reached as much as 50 mW with a pulsewidth of 113 ps when the average power of the IDL was 3 mW with a pulsewidth of 95 ps. The pulsewidth was measured using a non-colinear background-free second harmonic autocorrelator with a KDP crystal. The autocorrelation curve is shown in Fig. 5.

The spectral characteristics of the IDL and amplified output were compared. The overall linewidth of the IDL directly from the SCDL was about 10 nm with well-defined longitudinal modes separated by 0.55 nm and the individual mode was about 0.34 nm wide. The 578 nm spectral line of the CuBr laser was contained in one longitudinal mode [6]. The linewidth of the amplitied output was measured with a 4 mm thick F–P interferometer and it was about 7 GHz which is nearly the same as the linewidth of the 578 nm line from our home made CuBr laser seen by viewing the F–P interference fringes with a simple lens system. This value is sonewhat less than that measured by other researchers [8]. There is nearly no background noise measured here except for the amplified short pulse of 578 nm. There are two possible reasons: One involves the oblique axis geometry. The other is that the spectral region of the IDL was suppressed by a nonlinear process in the gain medium of the CuBr laser. In this case, the amplification factors indicated in Fig. 4 cannot reflect reality since the spectrum of the 578 nm amplified output was only 7 GHz and that of the IDL was about 10 nm wide. The resultant amplification factor was estimated to be 10^4, which is approximately equal to that measured in the case of small signal amplification [9]. It is evident from the above measurement that the product of the pulsewidth and the linewidth of the amplified output pulses was about 0.8. As is well known, if a pulse shape is assumed to be a Gaussian function, the corresponding product for a Fourier-transform-limited pulse should be 0.44. Comparing with this, it can be seen that nearly Fourier-transform-limited pulses have been obtained.

The discrepancy between the two values, 0.44 and 0.8, may be because the IDL pulses coming from the SCDL cannot be described by a standard restricted pulse form (such as Gaussian, $sech^2$, etc.) [6], and moreover, the pulses were much distorted by amplification through the active medium of the CuBr laser. For further study of this case, it is necessary to monitor the pulse shapes of the IDL and amplified output simultaneously. This work is now in progress.

Discussion and Conclusion

In the above experiment, there is an obvious broadening of the pulsewidth by the amplifier. The pulsewidth of the IDL has once been decreased much below 95 ps, but the pulsewidth of the amplified output was not changed greatly, i.e. it was still in the vicinity of 100 ps. This implies that pulse broadening will be more serious for shorter pulse lengths. It is not clear at the present time what is the main factor determining the pulse broadening.

We have shown for the first time that, by using an injection amplification method, nearly Fourier-transform-limited picosecond pulses of CuBr laser can be produced and the output power has reached as much as 50 mW. One expects that the output power can be made high enough for practical applications by using cascade amplificiation of other synchronized CuBr lasers.

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