STABILIZATION OF AN AM MODE-LOCKED TEA CO_2 LASER

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An increased shot-to-shot reproducibility has been obtained by injection of radiation from a cw CO_2 laser in an amplitude mode-locked TEA CO_2 laser without additional pulse broadening. Stable pulses variable from 900 ps up to 4 ns have been generated with this new technique.

1. Introduction

Active amplitude mode-locking is now a commonly used method for producing short pulses with several types of lasers. In pulsed lasers it has to be ascertained that the equilibrium-pulse duration is reached during the build-up time of the pulse. For a short duration of the inversion density in a pulsed system this can be a problem. It turns out that in such cases the production of stable, reliable pulses is highly dependent on the initial start condition for the radiation field to be generated.

Normally, the laser starts to oscillate from noise produced by spontaneous emission. Therefore, the build-up time of the radiation field in the cavity must be sufficiently long to ensure enough passes through the modulator, gain medium and resonator to filter out frequency components which are non-resonant or do not have the proper phase correlation. This condition is not always satisfied for pulsed laser systems like TEA CO_2 and Nd-YAG because of the relatively fast growing gain. Especially at low values of the modulation depth the time needed to reach a stable, reproducible pulse form is relatively long.

To generate stable pulses with increased shot-to-shot reproducibility in pulsed laser systems one can replace the noise as a start signal by a well defined radiation field. Several techniques have been proposed: a small pulse with low intensity, already travelling in the cavity when pumping starts [1] or the insertion of a gain section in the cavity with a band-width as small as the longitudinal mode spacing [2]. In the latter method a low-pressure CO_2 laser gain section with a continuous discharge was inserted in the cavity of an AM mode-locked TEA CO_2 laser. The mode-locking started now from the radiation frequency within the low-pressure band, which led to stable pulses for a large range of the modulation depth.

A disadvantage of this technique is the additional pulse broadening due to the small band-width of the low-pressure gain cell.

In this contribution we will introduce another method for generating stable, reliable pulses with an AM mode-locked TEA CO_2 laser, where the pulse-width is limited by the band-width of the TEA gain section. This is done by injection of monochromatic radiation in the TEA laser.

2. Experimental apparatus

The experimental configuration is schematically shown in fig. 1. The TEA laser is a 5×5 mm^2 discharge of 30 cm length, sealed with ZnSe Brewster windows. The laser operates with a mixture of 18% N_2, 18% CO_2, and 64% He, at 1 atmosphere total pressure. The germanium acoustooptic modulator is driven by a power generator operating with a frequency of 40 MHz. The modulation depth can be varied by changing the RF power of the power generator. The modulation depth is calibrated by observing the response on a pulse containing a single axial mode,

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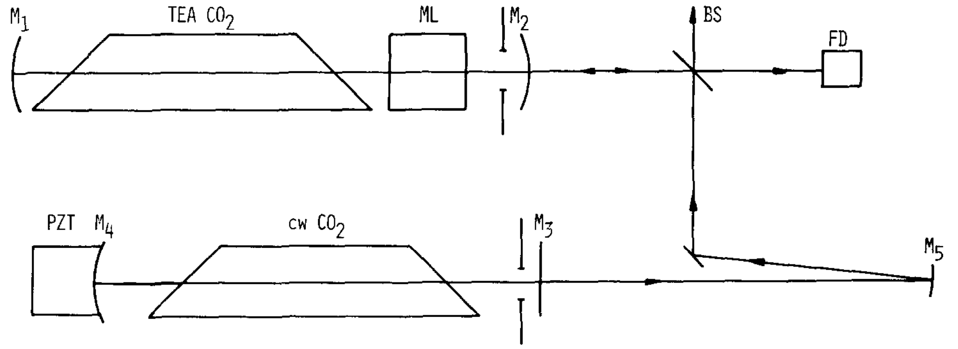

Fig. 1. Experimental set-up. M_1: Au mirror, 3 m radius. M_2: Ge mirror, 50% reflectivity, 2.5 m radius. M_3: Ge mirror, 90% reflectivity, flat. M_4: Au mirror, 2 m radius. M_5: Au mirror, 5 m radius, used for mode-matching. BS: Ge beam splitter, 50% reflectivity. ML: Ge acoustooptic modulator. FD: photon drag detector. PZT: piezoelectric transducer.

generated with an injection-locked TEA CO_2 laser oscillator [3].

The sealed-off low-pressure cw laser runs on a single axial mode of about 1 Watt. The frequency of this radiation is tuned by changing the length of the resonator with a piezotransducer. This radiation is injected into the TEA-laser cavity through the outcoupling mirror, by using mode-matching optics and a 50% beam splitter.

The output of the TEA laser is measured with a photon drag detector and a Tektronix transient digitizer. The total rise-time of the detection system is estimated to be about 500 ps.

3. Results and discussion

With the mode-locker switched off, the cw laser was tuned to achieve single longitudinal mode operation of the TEA laser. This wás shown by a smooth output pulse that was free from any mode-beating phenomena. In the case that the mode-locker was switched on, stable short pulses were observed even at low values of the modulation depth. In the upper part of fig. 2 two pulses of the train are shown for four successive shots in the absence of cw injection. The lower part of fig. 2 displays the same observation as in the case of cw injection. It was observed that the laser generated stable pulses with high shot-to-shot reproducibility during a large number of shots before, by thermal instabilities of the two cavity lengths, the frequency of the cw laser needed to be readjusted. It

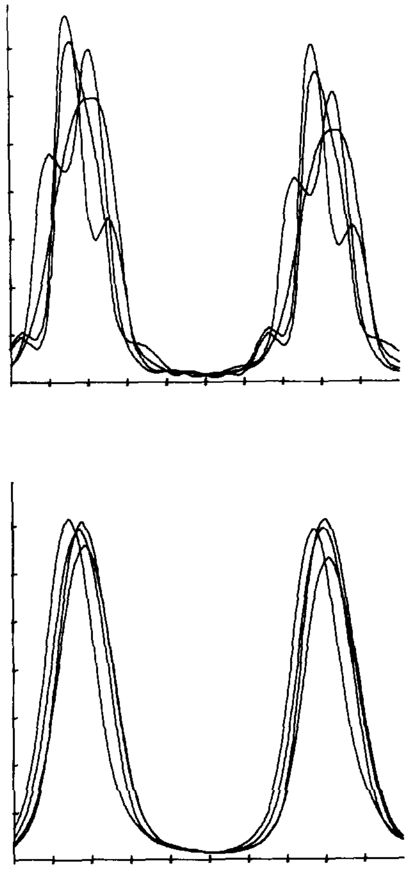

Fig. 2. Output pulses of four successive shots, with cw laser blocked (upper) and with cw injection (lower). Time scale: 2 ns/div. Modulation depth: 0.07.

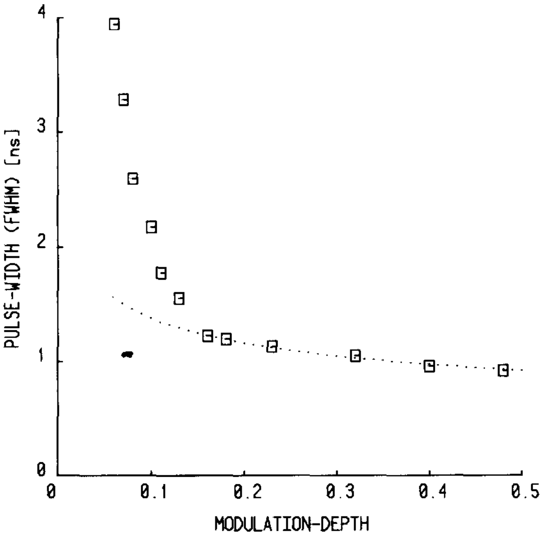

Fig. 3. Pulse-width as a function of modulation depth with cw injection. The dotted curve is the analytical solution (without cw injection) given by formula (2).

is expected that this can be improved by using standard cavity stabilization techniques.

The detuning range of the cw laser was not critical for obtaining reliable pulses. Furthermore, with this technique we found the same advantages as mentioned with the hybrid mode-locked laser as described in ref. [2], except that in our case we did not observe any broadening of the pulses at high modulation depths as a result of the additional cw injection. Instead, for high values of the modulation depth we found the same relationship of the pulse-width and the modulation depth as found in the absence of injection.

Fig. 3 shows the results of pulse-width measurements as a function of the modulation depth (δ), defined by the transmission function of the modulator [4]:

$$T(t) = \exp\{-2\delta \sin^2(\omega_m t + \theta)\},$$
$$\omega_m = 2\pi f_m. \qquad (1)$$

By changing the modulation depth we could vary the pulse-width from about 0.9 ns up to 4 ns. In this figure the theoretical curve [4] is plotted as well:

$$\tau_{FWHM} = \frac{[\sqrt{2}\ln 2]^{1/2}}{\pi}\left(\frac{g}{\delta}\right)^{1/4}\left(\frac{1}{f_m \Delta f}\right)^{1/2}, \qquad (2)$$

with Δf, g the band-width and gain of the TEA section, respectively, and f_m the frequency of the modulator.

It is seen that for $\delta > 0.15$ the experimental results are in agreement with this prediction. For $\delta < 0.15$, however, a large difference with the theoretical expression was observed.

It is believed that because at low values of the modulation depth the pulse compression per roundtrip is smaller than at higher values, more roundtrips are required to reach a steady-state condition.

In conclusion, we can say that this mode-locking technique improves the shot-to-shot reproducibility almost equally as with the hybrid laser [2], but has the additional advantage of no pulse broadening at high modulation depths.

References

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