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Publisher’s version / Version de l'éditeur:
https://doi.org/10.1063/1.89312
Applied Physics Letters, 30, 3, pp. 148-150, 1977

To be published in
Applied Physics Letters
15 January, 1977

A Simple Mode-locking Technique for Large Aperture TEA CO_2 Lasers

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Abstract

A large aperture, unstable resonator TEA CO_2 oscillator has been mode-locked by injection of nanosecond pulses chopped from the 1 watt output of a CW CO_2 oscillator. Power gains of $\sim 10^{12}$ and a locking window of ~ 200 ns have been observed.

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Mode-locking of large aperture, unstable resonator, TEA CO_2 lasers has permitted the generation of near diffraction limited multigigawatt pulse trains.[1,2] This has been achieved by injecting into a 'slave' laser resonator either a low energy train of nanosecond pulses or a single nanosecond pulse generated by an auxiliary ('master') mode-locked laser. Although this technique has provided an effective method for mode-locking large aperture oscillators, its use is complicated by the requirement for an additional mode-locked laser. Furthermore, in order to avoid degradation of the gain-switching action in the mode-locked slave,[1] it is necessary to limit the intensity of the injected radiation, and in most cases only a fraction of the energy generated by the master oscillator is required.

So far none of the experimental data which have been reported gives a clear indication of the minimum power required for injection mode-locking. However, recent experiments[3,4,5] on single longitudinal mode selection by injection locking indicate that CW powers considerably less than 1 watt can influence the frequency spectrum of the slave oscillator. Such observations suggest that the gated output of a CW CO_2 laser should be sufficient for injection mode-locking and indeed such a simplification of the technique has been proposed.[1]

In this paper we wish to report the experimental observation of injection mode-locking of a high power TEA CO_2 laser using a short pulse chopped from the attenuated output of a lower power CW CO_2 laser. The experiment was carried out on a UV preionized TEA CO_2 discharge module which was situated within a positive branch confocal unstable resonator (Fig. 1) consisting of a 6 m radius of curvature concave mirror and a 1.5 m radius of curvature convex mirror. The one metre long gain medium had a cross section of 7.5 × 7.5 cm and provided peak small signal gains of ∿5.5% cm^{-1} with a risetime of ∿1 μs.[6] Using a laser gas composition of 1:1:4, $CO_2:N_2:He$ the gain-switched output of this large aperture oscillator contained a total energy of ∿50 J and a typical pulse recorded by means of a photon drag detector and Tektronix 7904 oscilloscope is shown in Fig. 2(a). An injection signal was provided by electro-optically gating the multimode output of a 1 watt CW CO_2 laser operating on the 10.6 μm P20 transition. The CW radiation entering the TEA laser resonator was controlled by means of a GaAs Pockels cell [5 mm × 5 mm × 43 mm] and a germanium polarizer stack. Fig. 2(b) shows the electrical pulse applied to the GaAs crystal when a short length of charged line was switched by means of an electrically triggered spark gap. The triggering of this gap was referenced to an optical pick-up on the final spark gap of the TEA laser Marx bank and a jitter of ∿50 ns with respect to the oscillator output pulse could be obtained. The pulse gated from the CW beam was coupled into the unstable resonator through a 3 mm hole in the concave mirror. With the germanium polarizer stack adjusted for maximum transmission a peak CW CO_2 power between 100-200 mW was measured inside the resonator and it is estimated that only a small fraction (∿1%) of this power was coupled into the lowest order unstable resonator modes.

When a 1.5 ns electrical pulse, with an amplitude corresponding to only one quarter of the half wave voltage, was applied to the GaAs Pockels cell, a train of mode-locked pulses (Figs. 2(c) and 2(d)) having approximately the same total energy as the gain-switched pulse was generated. Some deterioration in the quality of the pulses can be seen near and subsequent to the peak of the oscillator output. This was due to the combined effect of the injected pulse shape and the non-linear amplification experienced by the pulse as the gain saturates. In this case, the injected energy was less than 10^{-11} J and it is estimated that the peak pulse in the train contains ∿10 J. Even with such low injected energies the timing window for mode-locking was approximately 200 ns wide and the histogram in Fig. 3 shows the fraction of mode-locked shots obtained for various times of injection.

Within the mode-locking region approximately 10% of the shots did not show complete mode-locking when the laser output was monitored by means of a photon drag detector and Tektronix 466 oscilloscope. This appears to have been due to the poor rejection ratio (10^{-2}) of the electro-optic gate which resulted in a background energy comparable to that of the injected pulse entering the slave laser during the 200 ns injection window. When the CW frequency corresponds to a longitudinal mode of the unstable resonator the energy of that particular mode is strongly enhanced and builds up in competition with the injected pulse. It should be noted, however, that the cavity itself discriminates against the background radiation when the CW laser frequency does not correspond to one of the longitudinal modes[5] and in fact it was found experimentally that even with the polarizer stack removed mode-locking occurred with a probability of ∿50%.

The results described above demonstrate that an extremely simple injection mode-locking technique can be used to control the output of a large aperture TEA CO_2 oscillator. The same technique has been applied successfully to mode-lock a small multi-atmosphere TE CO_2 laser up to pressures of 4 atmospheres.[7] Clearly a similar approach can be employed with other laser systems and offers an attractive alternative to conventional mode-locking techniques.

Acknowledgement

The authors acknowledge several stimulating discussions with Dr. P.-A. Bélanger and thank Drs. J.R. Izatt and J.-L. Lachambre for making available details of their unpublished results. Valuable technical support throughout the experiment was provided by D.A. Joines and K.E. Leopold.

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Figure Captions

Fig. 1. Experimental configuration used to injection mode-lock large-aperture slave laser.

Fig. 2. Oscilloscope traces illustrating injection mode-locking (a) gain switched output of the slave laser with no injected signal - horizontal scale is 10 ns/division. (b) Voltage pulse applied to the GaAs Pockels cell - horizontal scale is 5ns/division, vertical scale is 2900 V/division (c) pulses just prior to the peak of the injection mode-locked pulse train - horizontal scale is 2 ns/division (d) injection mode-locked pulse train - horizontal scale is 10 ns/division.

Fig. 3 Histogram showing the percentage of output pulses from the slave laser that are mode-locked plotted as a function of the relative switching time of the GaAs Pockels cell. The timing reference is taken from an optical pickup on the final spark gap of the Marx generator, and the output pulse occurs approximately 350 ns after the time of injection.

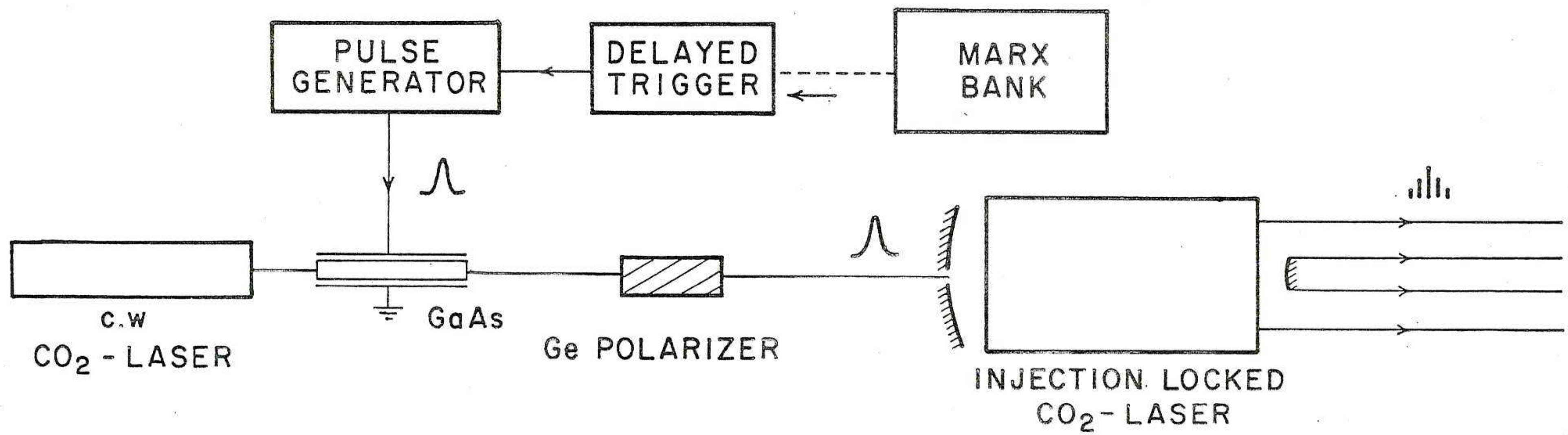
PULSE GENERATOR
DELAYED TRIGGER
MARX BANK
c.w
CO2 - LASER
GaAs
Ge POLARIZER
INJECTION LOCKED
CO2 - LASER

Fig. 1

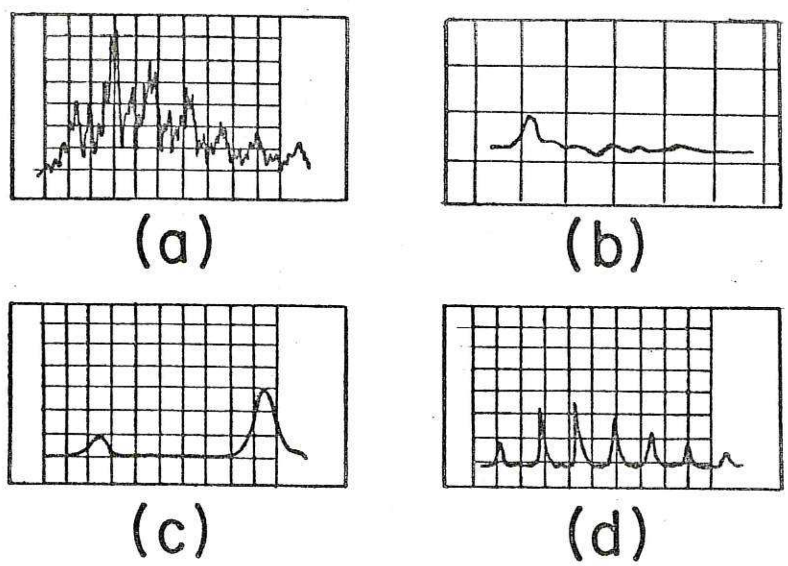

Fig. 2

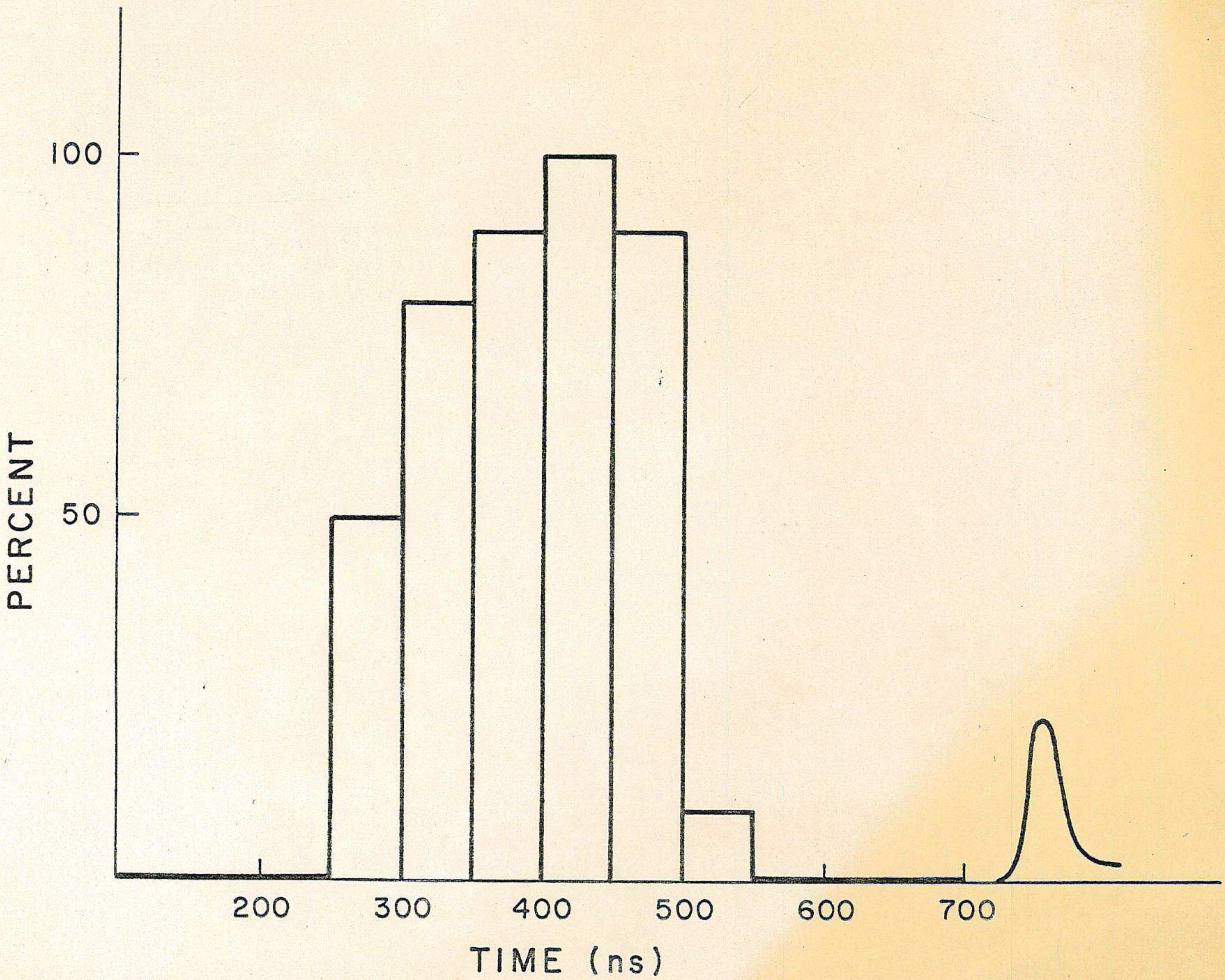

Fig. 3