INCREASED RELIABILITY OF PASSIVE MODE-LOCKING A MULTI-ATMOSPHERE TE CO_2 LASER BY INJECTION MODE-LOCKING

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Received 20 May 1985; revised manuscript received 18 November 1985

By injection of nanosecond pulses from an AM mode-locked TEA CO_2 laser in a passive mode-locked multi-atmosphere TE CO_2 laser the shot-to-shot reproducibility of the generated subnanosecond pulses was increased to almost 100%.

Passive mode-locking of the TE CO_2 laser has been demonstrated by a number of authors [1–3] using several types of saturable absorbers. The shortest pulses have been generated using p-type germanium yielding pulses as short as 400 ps at one atmosphere gas pressure [4] and 150 ps at ten atmospheres [3]. Reproducible passive mode-locking can only be achieved when the laser parameters are carefully adjusted as shown for example by Haus [5] and Taylor et al. [6]. The most important conditions required for stable passive mode-locking are the location of the saturable absorber, it must be placed at one end or in the middle of the cavity; the laser should operate just above threshold with only axial modes, the linear losses of the cavity must be dominated by the small signal loss of the saturable absorber. As the intensity of the biggest fluctuation has to saturate the absorber before the gain saturates and as the saturation intensity of p-type germanium is usually of the same order of magnitude as the saturation intensity of the gain medium [7], the beam diameter at the absorber must be smaller than in the amplifier. Since the number of fluctuations with comparable intensity in the time window given by the roundtrip time increases with pressure [6] and the gain period decreases with pressure it is more difficult to obtain reproducible pulses with passive mode-locking at higher pressure.

In this contribution we describe a method to increase the reproducibility of passive mode-locking in a multi-atmosphere TE CO_2 laser. The method is es-

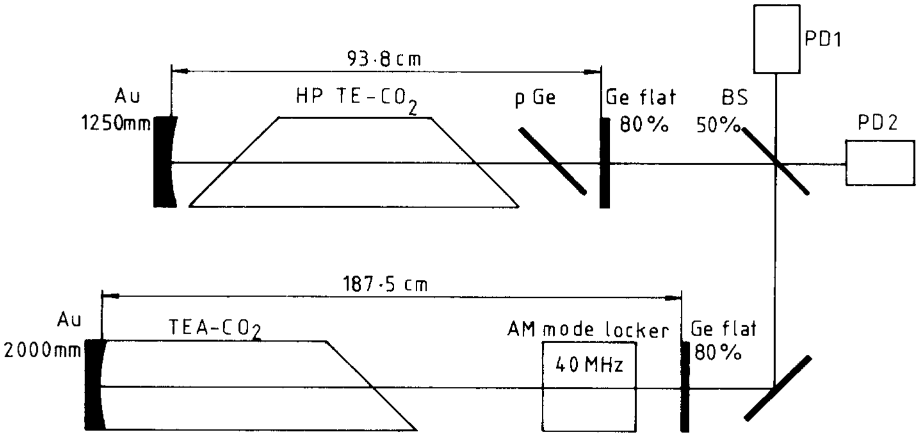

Fig. 1. Experimental configuration.

sentially injection mode-locking [8] with a p-type germanium saturable absorber placed in the resonator of the regenerative amplifier.

The experimental configuration is shown in fig. 1. The master oscillator was a 1 × 1 × 20 cm^3 UV preionized TEA CO_2 discharge operating with a 1:1:3 = $CO_2:N_2:He$ mixture at one atmosphere total pressure. A germanium acousto-optic modulator driven by a 40 MHz lithium niobate crystal caused amplitude modulation. As a result the laser produced a train of one nanosecond duration pulses on the 10.6 P(20) transition with a total energy of about 100 mJ.

The pulses, coming from the master oscillator were injected in a multi atmosphere TE CO_2 slave oscillator through the outcoupling mirror. This laser consisted of a 0.5 × 0.5 × 30 cm^3 UV preionized TE CO_2 discharge [9] operating with a 1:1:10 = $CO_2:N_2:He$ gas mixture at total pressure ranging from one to ten atmospheres.

The p-type germanium saturable absorber used was a 1.2 mm thick plan parallel plate placed at the Brewster angle as close as possible (≈7.5 cm) to the outcoupling mirror. The measured small-signal absorption of the 1 Ω cm p-germanium was 0.27 mm^{-1} and the saturation intensity was about 10 MW cm^{-2} [7].

In the case of no-injection the system with saturable absorber operates just above threshold at one atmosphere gas pressure and produces pulses shorter than one nanosecond. However, about 30% of the pulse trains contained more than one pulse of comparable intensity in the roundtrip time window. Furthermore the reproducibility was poor. Fig. 2 shows an example of one of the best shots at one atmosphere. At increased gas pressures there was no reliable mode-locking possible with this configuration. However, when the pulse train from the master oscillator was injected and the delay between the two discharges was properly chosen we observed for almost all shots reliable pulses. In fig. 3 we display some of the strongest pulses in the train with widths shorter than 760 ps, the response time of our photondrag detector and Tektronix 7912 AD transient digitizer detection system.

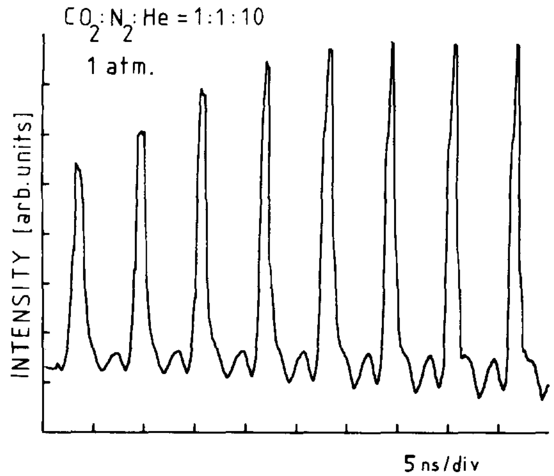

Fig. 2. Part of the pulse train from the passive model locked TE CO_2 laser operating at one atmosphere gas-pressure without injection of an external pulse train.

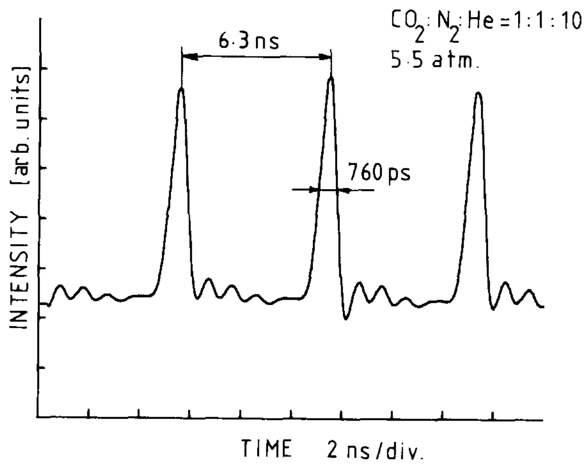

Fig. 3. Pulses from the passive mode locked laser with injection of one-nanosecond pulses from the AM mode locked TE CO_2 laser.

Reliable pulses were observed at all gas pressures of the slave oscillator ranging from one to ten atmospheres However at high pressure operation the p-type germanium absorber as well as to the germanium outcoupling mirror were damaged.

In conclusion we have demonstrated a method to enhance the reproducibility of generating subnanosecond pulses with a combination of passive- and injection mode-locking. We found that, using injection mode-locking, the conditions for good passive mode-locking are no longer stringent so that probably a larger beam diameter at the p-germanium can be chosen to avoid damage.

This work was sponsored by the organization for fundamental research of matter (FOM), the Netherlands.

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