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# Mode-locking of a Semiconductor Laser with a Multiple-mode Interference Waveguide

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Passive mode-locking of laser based on nonlinear coupling in a directional coupler has been proposed and implemented in Erbium-doped fiber laser systems. In a previous publication of ours, we have also numerically shown the possibility of mode-locking semiconductor lasers based on the similar mechanism. When a long pulse enters a directional coupler made of two parallel traveling-wave semiconductor optical amplifiers, the weak leading tail will be coupled into the cross port and amplified. However, the central high-power part will induce gain saturation and refractive-index change in the input amplifier and break the phase-matching condition for linear coupling. Therefore, the central high-power part of the input pulse stays in the bar port and may receive a certain gain. The trailing tail of the input pulse also stays in the bar port and is effectively suppressed because of the long recovering time of gain saturation. Hence, the pulse emerging from the bar port is effectively compressed. By circulating such a compressed pulse in a cavity, we can achieve mode-locking.

In this paper, we present our experimental results of mode-locked GaAs/AlGaAs quantum well semiconductor lasers based on the similar phenomenon. We used a multiple-mode interference (MMI) coupler, instead of a coupler composed of two separate waveguides. Such a MMI coupler is nothing but a multiple-mode waveguide (amplifier) in which the beating of different waveguide modes leads to different transverse wave field distributions at different propagation distances. When gain saturation occurs, the wave field distribution is changed resulting in a phenomenon similar to nonlinear coupling in a directional coupler. Our laser setup is shown in Fig. 1 in which the 500 μm-long semiconductor amplifier has two sections: the narrower one has the width 4 μm and length about 400 μm and the broader one has the width 8 μm and length about 100 μm. It was estimated that there existed two waveguide modes in the broader section. To reduce the multiple-reflection effects from the end faces of the semiconductor chip, the waveguide tilts from the normal to the cleaved facet by 12°. The total cavity length is 60 cm leading to a pulse repetition period about 4 nsec (250 MHz). Figure 2 shows the L-I curve indicating that the threshold current for cw oscillation is 90 mA and the efficiency is 2.4 %. Near 120 mA, there is a kink which was then proved to be the threshold current for pulsed oscillation. Figure 3 shows the spectrum of cw operation with the injection current at 110 mA. We can see the coexistence of two narrow spectral features. We are not sure at this moment whether they come from mode hopping or stable two-wavelength operation. When the current increased to 130 mA, a pulse train with a period 4 nsec, which was consistent with the cavity length, was observed, as shown in Fig. 4. It is a first proof of mode-locking (we have changed the cavity length from 30 to 60 cm and found that the pulse repetition period was always consistent with the cavity length that indicated that the pulse train was not due to self-pulsation). The mode-locking process was then confirmed by the observation of the spectrum at this injection current, as shown in Fig. 5. Here, we can see the blue-shifted and broadened spectrum. The blue shift was usually observed with increasing injection current. The

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broadening of spectrum is another proof of mode-locking. We are currently measuring the autocorrelation, which might be difficult because of the low output power. Also, we are conducting theoretical and numerical studies to make sure the mode-locking mechanism. There may exist other mode-locking mechanisms leading to the observed results.

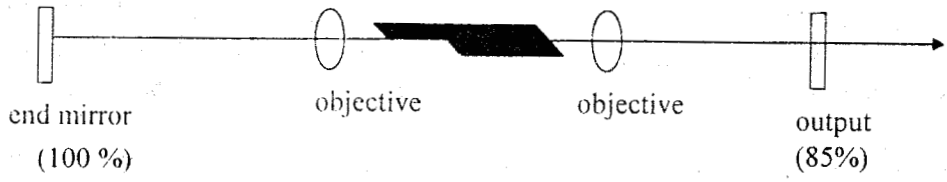


Fig. 1 Laser setup for mode-locking.

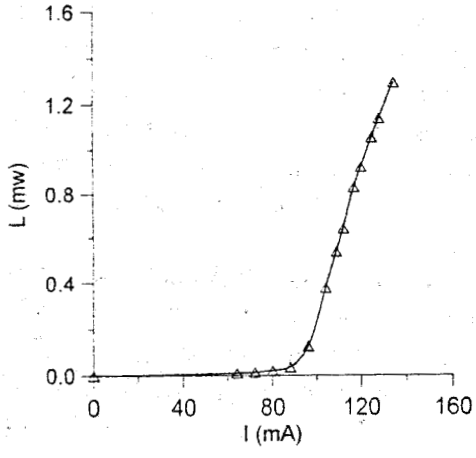


Fig. 2 L-I curve of the laser.

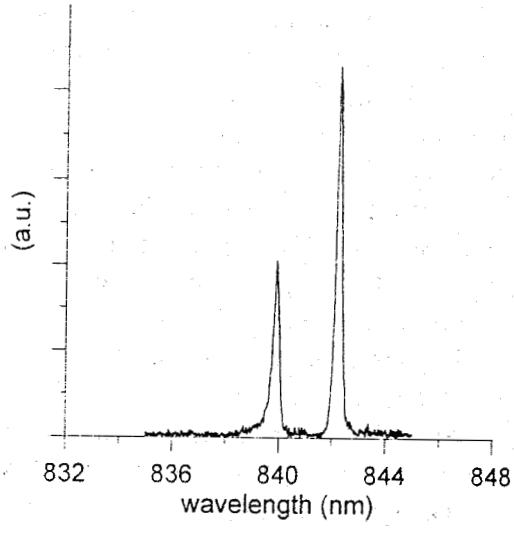


Fig. 3 Spectrum of CW operation.

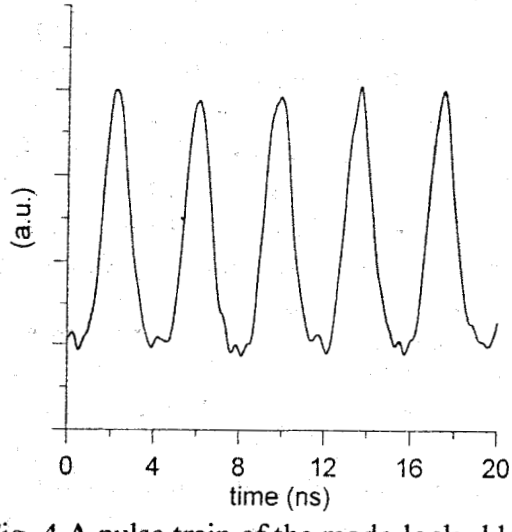


Fig. 4 A pulse train of the mode-locked laser.

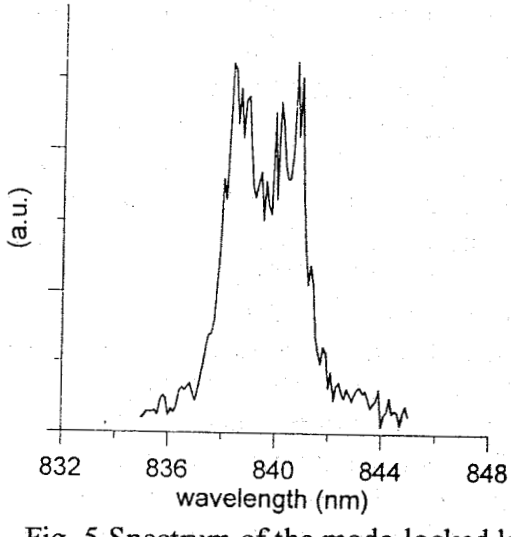


Fig. 5 Spectrum of the mode-locked laser.