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Mode Locking of Semiconductor Laser with External Cavity

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Mode locking of semiconductor laser with external cavity has been observed by optoelectronic feedback. to p 7

In the last few years, the super-short pulse generated by a semiconductor laser (LD) is extremely encouraging. The sizes of this sort of device are small; it can be applied in the fields of fiber optic communications, high speed electronics, and response time inspection for a detector as well as time domain measurement for fiber optics. There are three types of super-short pulse generating methods for a semiconductor: 1. Locking mode of a semiconductor laser with external cavity. When a modulated alternating current (AC), frequency f_r, flows across a semiconductor laser, and if f_r is equal to or integer times of the frequency of the longitudinal mode, an active locking mode can be achieved [1]. A passive locking mode can be accomplished by using an aged LD or an LD whose end surface has been subjected to proton bombardment [2]. 2. Direct electric excitation [3]. A super-short light pulse can be obtained due to gain switching effects when a strong current of tens times the pulse width or a strong sine current is applied to a LD. 3. Optoelectronic feedback [4]. After the output light from a self-pulsing LD is converted to an electric signal by passing it through a photodiode, the signal is then amplified and fedback to the LD, an optical pulse of 10 20 ps can then be obtained (as shown in Fig. 1). The optical and the power supply systems are simplified by adopting this method; however, a strong self-pulsing LD is required.

It is inevitable to have impurity and defects existing in a semiconductor crystal which forms electron traps in the forbidden band. When a positive current flows across the semiconductor, the electron population increases in the conduction band, at the same time, the electron trap will be able to catch some electrons. The electron caught by the trap can escape from it and jumps to the conduction band after absorbing a photon, which increases the carrier density. The higher the light intensity, the larger this effect. Moreover, the electron trap can catch additional electrons while the electron in the condition band makes a non-radiant jump to the valence band. The physical processes stated above, as well as the saturating gain effect, can induce an periodical adjustment of the carrier density in the LD, and consequently generate a light pulse (as shown in Fig. 2). The pulse amplitude depends upon the electron trap density, T_0. If T_0 is too small, the pulse will be too weak to be detected . This sort of LD can not be used in an optoelectronic feedback to generate a super-short pulse.

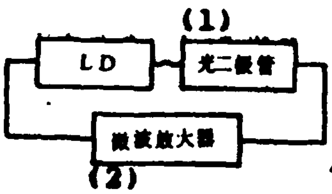

Fig. 1 The block diagram of the optoelectronic feedback principle.
Key: (1) Photodiode;
(2) Microwave amplifier.

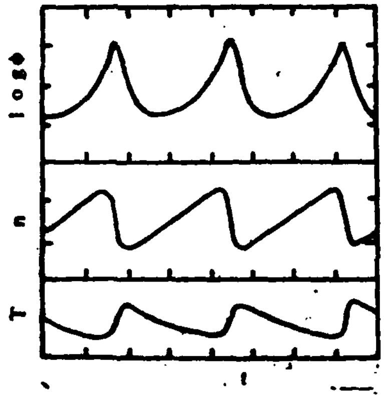

Fig. 2 Illustration of a self-pulsing process.
n: electron density, Φ: photo density, T: empty electron trap density, t: time.

This paper presents a super-short pulse generating method by feeding the light-induced pulse, which is generated by a semiconductor laser with external cavity, back to the LD after passing through an optoelectronic conversion. When an external cavity is formed by an LD and an external mirror, an oscillating gain in the LD will be established by the periodic photo feedback and the electronic trap effect, and consequently create an induced self-pulsing. The cavity length has a direct bearing on the frequency, amplitude and pulse width of the induced self-pulsing [7]. The self-pulsing will be suppressed when the pulse is short. The self-pulsing strength can be increased if the cavity is over a certain length. Even for those LDs without a self-pulsing, a stronger self-pulsing can be obtained after an external cavity is attached. The test has proved that an LD will be able to generate an induced self-pulsing generally after an external cavity is added. Therefore, the concept of the optoelectronic feedback method for a semiconductor laser with an external cavity makes sense. The frequency of the induced self-pulsing, $f = mc/2L$, L is the external cavity length, c is light speed, m = 1, 2, 3 ·····, the magnitude of m depends on the cavity length and the current. The frequency of the feedback electric pulse will be equal to or integer times of the frequency of light which travels back and forth in the external cavity. If the feedback is strong enough, an active mode-locking effect can be achieved. The mechanism of creating an induced self-pulsing is similar to but not exactly the same as the passive locking mode. In an experiment, the locking condition can be shown on a microwave spectrum. When it has not yet been locked, the microwave spectrum is wide because the frequency intervals of the longitudinal mode are not even. The spectrum width will be narrowing while being locked. The experiment shows that the longitudinal mode will be locked when the strength of the induced self-pulsing increases to a certain level, and this induced self-pulsing will be converted to a passive locking mode. If the electron trap density in an LD is high, or the density of the saturating absorption center is increased by using an artificial method such as photon bombardment, etc., the passive locking mode can be obtained. Thus the optoelectronic feedback can lead to an active-passive self-adjusting locking mode.

The experiment setup is illustrated in Fig. 3. A strip GaAlAs bi-impurity LD which has been through the photon bombardment treatment is used in the experiment. The length of the self-focus is 0.23 pitch, and the reflection mirror M_1 is coated with the full reflective medium. The current threshold of the LD itself is 74 mA, and it becomes I_{th} = 70 mA after a L ~ 34 cm external cavity is formed. A dynamometer is used to monitor the coupling effect of the external cavity. A Textronic 496 spectrometer is also used to view the self-pulsing frequency. The spectrum of the induced self-pulsing basically reflects the microwave spectral frequencies of the various modes of the output light. After the light signal is converted to an electrical signal in the APD 1, it is then amplified and fed to the LD. The signal is amplified 20 dB in the range of 300 ~ 550 MHz.

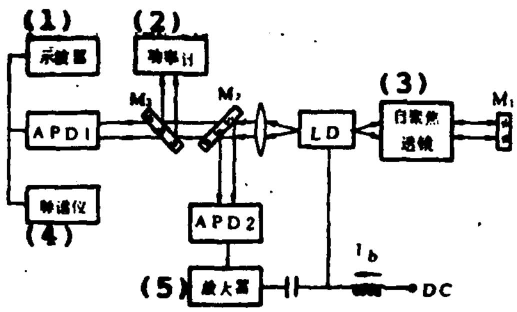

Fig. 3 Illustration of the experiment setup.
Key: (1) Oscilloscope; (2) Dynamometer; (3) Self-focus lens; (4) Spectrometer; (5) Amplifier.

The LD itself used in the experiment has no self-pulsing; only the wide band noise can be detected in the spectrometer. Figure 4a and 4c show the microwave spectrum of the induced self-pulsing of the semiconductor laser with a L ~ 34cm external cavity, when the device is subjected to various current conditions. The self-pulsing frequencies are 430 MHz and 436 MHz, and their spectral width, Δf are 18 MHz and 5 MHz, respectively. Figure 4b and 4d show the microwave spectrum which has passed through an optoelectronic feedback. It clearly indicates that the pulse amplitude is noticeably increased after the pulse has passed through the optoelectronic feedback. The microwave spectral width, Δf is reduced from 18 MHz to 2 MHz and from 5 MHz to [illegible] KHz, respectively. This phenomenon indicates longitudinal mode locking. When the longitudinal mode is fully locked, the lower limit of Δf should be equal to the the line width of the longitudinal mode. The line width of the longitudinal mode of a semiconductor laser with a flat external cavity whose length, L is approximately several centimeters and is approximately 1 MHz which is determined by using the autodyne method. The microwave band width after the optoelectronic feedback obtained in the experiment is close to the line width of the longitudinal mode. Owing to the time lag effect of the feedback signal, both pulse frequencies before and after feedback are slightly different.

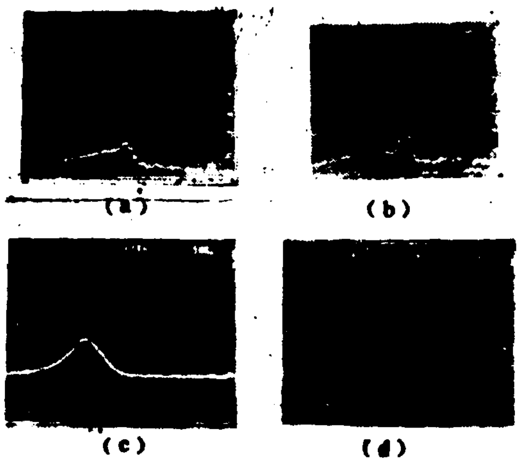

Fig. 4 An induced self-pulsing and the microwave spectrum of the output light after the optoelectronic feedback.
(a), (b) X-axis 5 MHz/grid, Y-axis 500 microV/grid;
(c) X-axis 5 MHz/grid, Y-axis 10 DB/grid;
(d) X-axis 2 MHz/grid, Y-axis 10 DB/grid.

Figure 5a, 5b show the variations of both the pulse amplitude, A_p, and microwave band width, Δf, along with the input current,

I_b for both cases with feedback and without feedback. The curves indicate that (1) the pulse amplitude and microwave band width are related to the input current when the cavity length is fixed. The maximum pulse amplitude and the minimum microwave band width can be obtained at a certain current value. Under this current, the positive carrier density reaches the optimum when the feedback light pulse in the external cavity rushes to the LD. If the current is too small, the carrier density still reaches the optimum condition when the light pulse arrives, and then the pulse amplitude will be low. The low amplitude is not sufficient to lock the nearby longitudinal mode interval at the peak frequency of the self-pulsing; therefore, the microwave band width is larger. If the current is too great, the carrier density has reached its optimum condition before the light pulse arrives, and forms an excited radiation. Part of the carrier is exhausted when the light pulse arrives, thus the light pulse is wider, and its amplitude is smaller. (2) The optoelectronic feedback makes the pulse amplitude increase and microwave spectrum decrease noticeably; consequently, mode locking is reached at the optimum condition. When the pulse amplitude is too small because of the weak feedback signal, the feedback effect is not noticeable.

Conclusion: The noticeable narrowing of the microwave spectrum explains the mode locking phenomenon which occurs when the optoelectronic feedback is sufficiently strong. A second order harmonic relating method or a strip camera can be used to measure the pulse width in order to positively identify the locking condition. After testing several LDs, the results show that most of the LDs possess a relatively strong induced self-pulsing at 1 GHz. A better result can be achieved if a 1 GHz amplifier is used and its magnifying power is increased. The experiment shows that an induced self-pulsing can be obtained from the LD, which originally has no self-pulsing, after an external cavity is formed; therefore, the optoelectronic feedback method for generating an induced self-pulsing is significant. If the semiconductor laser with an external cavity reaches the passive locking mode, an active-passive self-adjusting locking mode, which occurs owing to the automatic matching between the adjusting frequency and cavity length, can be achieved after the optoelectronic feedback.

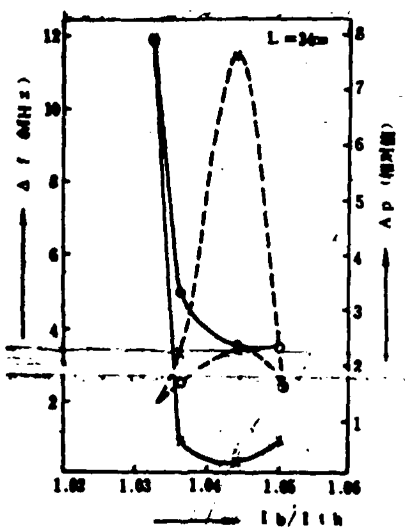

Fig. 5 The variation of the pulse amplitude, A_p, and microwave spectral width, Δf, vs. I_b.
(—$A_p \sim I_b/I_{th}$, —$\Delta f \sim I_b/I_{th}$, o -- without optoelectronic feedback, x -- with optoelectronic feedback)

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