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All-optical clock recovery using parallel ridge-width varied DFB lasers integrated with Y-branch waveguide coupler ☆

Duanhua Kong [a,*], Hongliang Zhu [a], Song Liang [a], Wenke Yu [b], Caiyun Lou [b], Lingjuan Zhao [a]

[a] Key Laboratory of Semiconductor Materials Science, Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, China
[b] Department of Electronic Engineering, Tsinghua University, Beijing 100084, China

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ABSTRACT

A novel device with two parallel ridge-width varied distributed feedback (DFB) lasers integrated monolithically with Y-branch waveguide coupler was fabricated by means of butt-joint regrowth. A 22 GHz self-pulsation tuning range has been achieved by adjusting independently the driving currents of the two DFB lasers sections. 38.4 GHz all-optical clock recovery has been demonstrated for the first time using this device.

1. Introduction

An LL optical 3R regeneration (re-amplification, re-shaping and re-timing) has been of great interest in optical communication applications with ever increasing data rate demands. This can be attributed to its capability for overcoming optical signal degradation in long haul transmission systems and the bandwidth limitation of electronic devices. All-optical clock recovery (re-timing) is one of the key technology components for all-optical 3R regeneration. In recent years, various all-optical clock recovery devices, such as the amplified feedback laser (AFL) [1], mode-locked lasers [2-4] and the dual-mode-laser with two independent distributed feedback lasers have been widely studied for all-optical clock recovery applications. The dual-mode-laser reported includes the multi-section [5-8] and the Y-branch configurations [9]. Compared with other device technologies, the dual-mode-laser is a highly promising candidate for all-optical re-timing, due to their desirable features such as compact sizes, convenient device tuning through simple DC injection current adjustments, wide tuning range and compatibility with future ultra high speed optical communications systems operating in the T-Hz range [10]. The dual-mode Y-branch DFB configuration has been used for microwave generation with a narrow line width and has been obtained [9]. This type of device is also expected to perform well in all-optical clock recovery. Compared with the cascade multi-section configurations, the Y-branch configuration is expected to offer better performance for all-optical re-timing, due to their merits including better electrical isolation between the two DFB laser sections and more balanced optical output power level from the two DFB laser sections. The injected power into the two DFB lasers can also be balanced by the Y-branch, making the new device to be much more easily injection locked.

In a previous paper a novel two-section self-pulsation DFB laser with a varied ridge width [11] has been reported. In this particular design, by simply varying the ridge width of the two DFB sections, an effective static wavelength detuning can be obtained, which is an important design target [12]. The DFB grating can be fabricated by the conventional holographic exposure method. This makes the device fabrication process much simpler and more cost-effective than the conventional approach, in which the static wavelength detuning is introduced by grating with different periods fabricated by electron beam exposure [12].

In this work, we fabricated the Y-branch self-pulsation DFB laser with varied ridge-width for all-optical clock-recovery. A 0.2 μm difference in the ridge-width of the two DFB sections allowed for self-pulsation signal generation at around 40 GHz. A self-pulsation frequency continuous tuning range from 22.5 to 43.75 GHz was achieved. We further demonstrated clock recovery at 38.4 GHz with a timing jitter of 632 fs using the device at optical injection power level as low as 1.6 mW. The successful all-optical clock recovery indicates that the ridge-width varied Y-branch self-pulsation DFB laser is a promising applicant for optical 3R regeneration systems.

2. Device design and process flow

As is shown in Fig. 1, the ridge-width varied Y-branch self-pulsation DFB laser consists of two-ridge varied multi-quantum well partly gain

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* Corresponding author.
E-mail address: kdh@semi.ac.cn (D. Kong).

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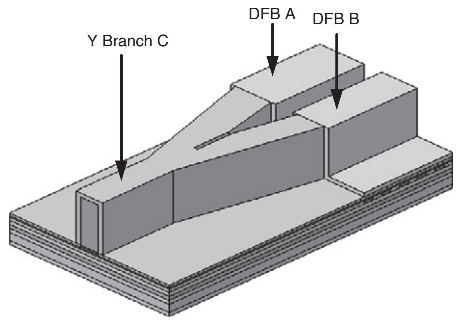

Fig. 1. Schematic diagram of the ridge-width varied Y-branch self-pulsation DFB laser.

coupled DFB laser sections. Outputs from the two sections are combined with a phase front accelerator Y branch coupler [13]. The ridge widths of the two DFB laser sections are designed to be 3.2 μm (sections A) and 3 μm (sections B) respectively for 40 GHz self-pulsation generation. The lengths of the DFB lasers and the Y-branch are 350 μm and 450 μm, respectively. The two DFB laser sections are separated with a 10 μm trench for optical and electrical isolation.

For the first epitaxial growth, an InP buffer layer, a 100 nm thick lattice-matched InGaAsP ($\lambda_{PL}=1200$ nm) lower optical confinement layer, an eight-pair InGaAsP/InGaAsP MQW structure, a 100 nm thick lattice-matched InGaAsP ($\lambda_{PL}=1200$ nm) upper optical confinement layers and a grating layer are grown successively on n-type InP substrate by MOVPE at 655 °C and 20 mbar pressure. The MQWs are composed of seven 1550 nm 1% compressively strained InGaAsP wells separated by lattice-matched InGaAsP 1.2Q barriers. The integration of the two DFB lasers and the Y-branch waveguide coupler was realized by butt-joint regrowth, in which the DFB sections on the wafer are protected by PECVD evaporated SiO_2 mask and the MQW active layers in the Y-branch region were selectively etched off. Afterward the passive waveguide epitaxial layers are grown, which include a 60 nm 1.2 Q lattice-matched InGaAsP layer, a 210 nm 1.3Q lattice-matched InGaAsP layer and another 60 nm 1.2 Q lattice-matched InGaAsP layer, forming the butt-joint interface with the unetched DFB sections. After the butt-joint regrowth a conventional first-order grating is partially formed on the DFB laser sections by holography technique and pattern transferred through a dry-etching process. A third-step MOCVD regrowth then followed, in which a p-type InP cladding layer and an p-type InGaAs contact layer were grown, completing the full epitaxial structure. Next the varied ridge width structure and the Y-branch ridge waveguide were defined by $CH_4/H_2/Ar$ RIE. Finally the sputtered Ti/Au p-type and evaporated Au/Ge/Ni n-type electrical contacts were formed, completing the process flow. All output facets of the device structure were formed by cleaving without additional dielectric coating.

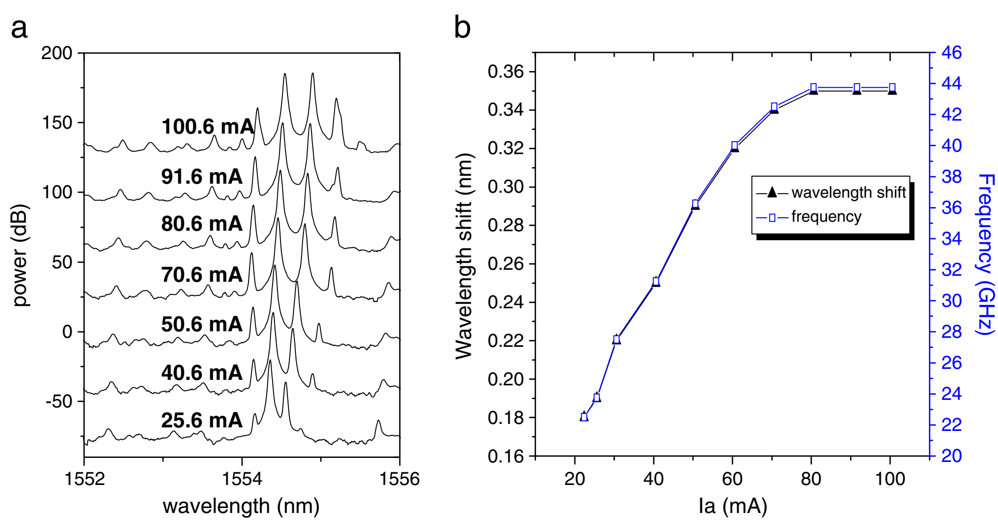

Fig. 2. (a) Typical optical spectra of the device. The biasing current in DFB section B is fixed at 92 mA while the biasing current I_A in DFB A is adjusted as denoted. (b) Wavelength difference between the two different optical modes and expected self-pulsation frequencies vs. I_A.

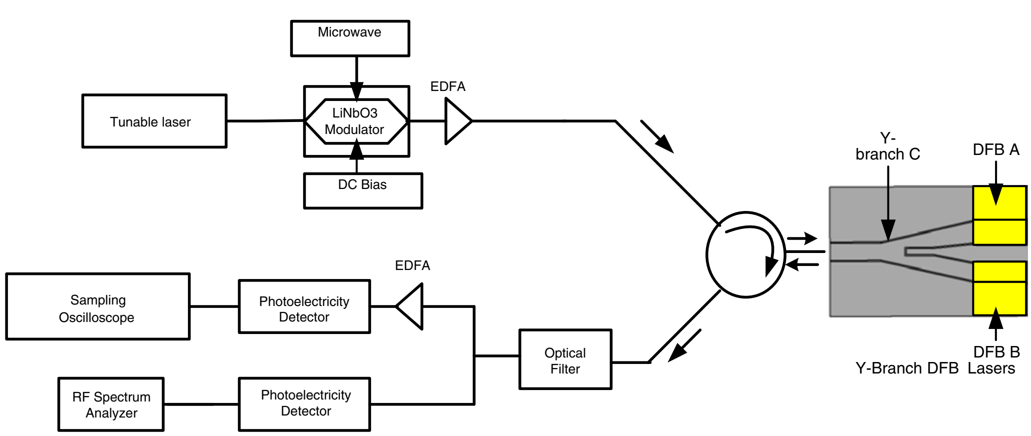

Fig. 3. Experimental setup for 38.4 GHz all-optical clock recovery.