Monolithic 45-GHz Mode locked Surface-Etched DBR Laser Using Quantum Well Intermixing Technology

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***Abstract*—45-GHz passively mode locked AlGaInAs/InP 1.55 µm lasers integrated with surface-etched distributed Bragg mirrors have been fabricated. Quantum well intermixing was used to provide low absorption loss gratings with accurate wavelength control. The lasers produce 3.6-ps Gaussian-pulses with TBP of 0.57.**

***Keywords*—mode locked laser; monolithic integrated circuits; surface-etched Bragg gratings; quantum well intermixing.**

I. INTRODUCTION

Semiconductor mode locked lasers are attractive as compact pulse sources in high-speed optical communication systems, microwave photonics, and high speed optical sampling. Distributed Bragg reflectors (DBRs) are indispensable for controlling the spectral bandwidth, the centre wavelength, and repetition rate tuning of the pulses. So far, conventional 40-GHz mode locked DBR lasers require at least one growth interruption, resulting in a low yield and higher cost per unit [1, 2]. Surface-etched DBRs require only a single epitaxial grown step, and can be simultaneously fabricated with the ridge waveguide. Therefore, the fabrication process is much simpler than the methods used in traditional DBR structures. In particular, Al-containing active layers can be used below the grating without the risk of oxidization. Larsson et al. [3] have demonstrated 10-GHz all-active monolithic mode locked lasers with surface-etched Bragg gratings, but the DBR coupling efficiency κ was very low ($\kappa \sim 7$/cm). Quantum well intermixing (QWI) permits post-growth modification of the QW band edge, offering a simple, flexible and low cost alternative technique to selective etching and re-growth. The refractive index discontinuity at the interface between adjacent sections is negligible, which eliminates parasitic reflections that can degrade performance [4]. Recent advances in the AlGaInAs/InP material system make it a more promising candidate due to better intrinsic characteristics in comparison with the conventional InGaAsP/InP material system [5]. In this paper, we present for the first time a monolithic 45-GHz passively mode locked AlGaInAs/InP 1.55 µm multi-quantum-well (MQW) laser integrated with surface-etched Bragg gratings with moderate coupling efficiency ($\kappa \sim 40$/cm), low absorption loss, and accurate wavelength control using a relatively simple fabrication approach. QWI technology was used to blue-shift the bandgap of DBR and phase section relative to the active sections, e.g. gain and saturable absorber (SA) section, to reduce the direct bandgap absorption.

II. DEVICE STRUCTURE AND FABRICATION

The epitaxial structure is described in [5]. The top $Al_{0.423}Ga_{0.047}In_{0.53}As$ (60-nm-thick) waveguide layer behaves as a reactive ion etching (RIE) etch-stop layer to define the height of the ridge waveguide, while reducing the RIE lag effect in the grating. The monolithic integrated mode locked DBR laser is shown in Fig. 1. The device has a total length of 1080 µm and consists of a 700-µm-long gain section, saturable

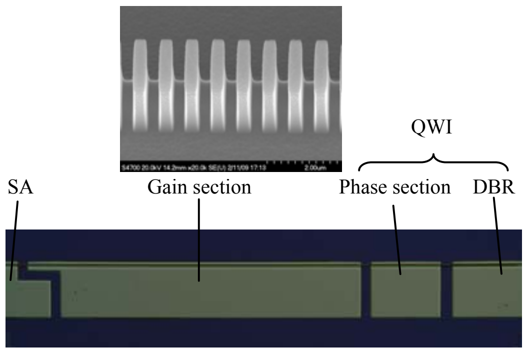

Figure 1. Optical microscope picture of monolithic AlGaInAs/InP mode locked DBR laser and SEM picture of 734-nm-period gratings.

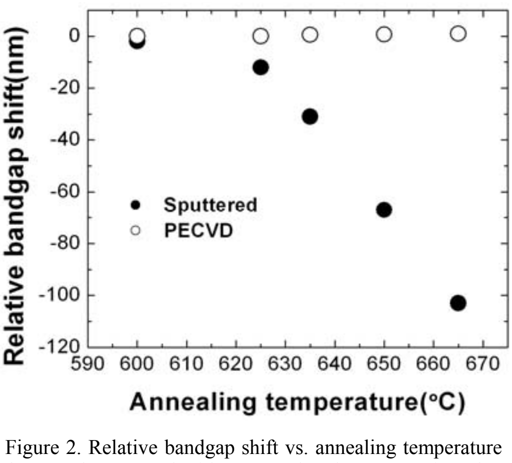

Figure 2. Relative bandgap shift vs. annealing temperature for samples covered with sputtered and PECVD SiO_2 after 60 seconds of rapid thermal annealing (RTA) process.

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absorber (20 µm), phase section (150 µm) and a DBR section (150 µm). Electrical isolation between the electrodes was obtained by wet etching 20 µm slots in the contact layer. A 200 nm of sputtered SiO_2 film was selectively deposited on the passive waveguide areas (DBR and phase sections) then the whole wafer was covered with a protective 200-nm-thick PECVD SiO_2 film. The sample was subsequently annealed at 660 °C for 60 seconds leading to a targeted bandgap shift of 100 nm for the passive section, while the gain and SA section did not exhibit any significant shift at the same rapid thermal annealing (RTA) temperature (see Fig. 2). The 2.5-µm-wide ridge and 3rd order gratings (367-nm-wide grating slots with 50% duty cycle) were defined by electron beam lithography and a CH_4:H_2:O_2 RIE dry etching process, terminated at the etch-stop layer (1.92 µm total ridge etch depth). Following the normal passivation, p-contact window opening, p-contact deposition, thinning and n-contact deposition, the sample was cleaved into individual laser bars with both SA facets and the DBR facets left uncoated. The devices were mounted epilayer-up on a copper heat sink and tested under CW conditions at a temperature of 20 °C.

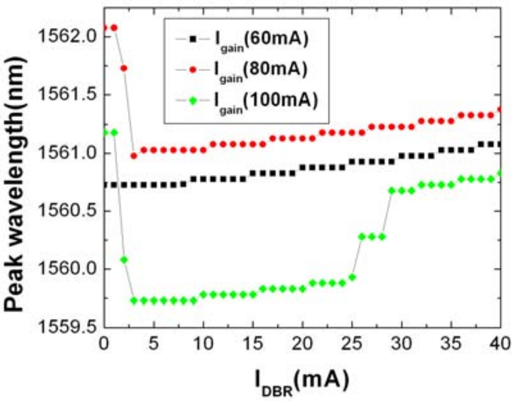

Figure 3. Emission peak wavelength vs. DBR currents for I_{gain} = 60, 80, and 100 mA, while the phase section is floating and V_{SA} = -2.0 V.

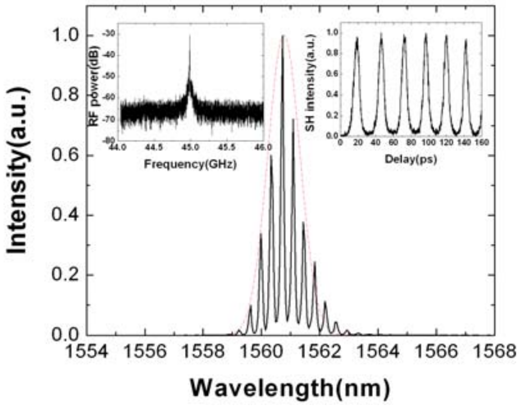

Figure 4. Optical spectrum, corresponding RF spectrum (left inset) and autocorrelation trace (right inset) for I_{gain} = 60 mA, I_{DBR} = 2 mA, phase section floating, and V_{SA} = -2.0 V.

III. DEVICE PERFORMANCE

Pure mode locking characteristics were observed when forward biasing gain section I_{gain} varied from 44 mA to 136 mA and SA reverse bias voltage $|V_{SA}| \geq 2.0$ V.

Fig. 3 summarizes the dependence of the peak wavelength on the DBR tuning current, where the total injection current to the gain sections and the absorber reverse bias were fixed at 60, 80, 100 mA and -2.0 V, respectively. The results clearly show that when I_{gain} is set to 80 or 100 mA, the peak wavelength is reduced as I_{DBR} increases from 0 mA to 3 mA due to the plasma effect. At higher DBR currents, the wavelength increases again due to heating effect. At discrete current levels a jump in wavelength occurs, which is equivalent to the length of one longitudinal mode (~ 0.35 nm). For I_{gain} = 60 mA, the plasma effect is less pronounced as the tuning was dominated by the heating effect.

The shortest pulse width was observed at I_{gain} = 60 mA, I_{DBR} = 2 mA, where the autocorrelation width of an isolated pulse was 5.1 ps, which deconvolves to 3.6 ps pulse duration if a Gaussian pulse shape is assumed. The period of the emitted pulse train measured is 22.2 ps, which is in accordance with the RF spectrum frequency of 45.0 GHz (see Fig. 4). The optical spectrum is centered at 1560.8 nm with a 3 dB bandwidth of 1.29 nm. The time-bandwidth product of the pulse is equal to 0.57, which is very close to the transform limit (≈ 0.441) of a pulse with Gaussian profile.

IV. CONCLUSION

In conclusion, we have fabricated and characterized a 45-GHz passively mode-locked AlGaInAs/InP 1.55 µm laser with highly selective and low-loss DBR mirrors by using QWI technology. The mode locking results show that our device offers a real alternative to and a cheaper solution than conventional DBR mode locked lasers.

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