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1.7 kHz RF linewidth III-V-on-silicon mode-locked laser

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***Abstract*—For the first time we demonstrate an anti-colliding mode-locked laser implemented on a III-V-on-silicon platform. In passive mode-locked operation a 1.7kHz 3dB linewidth of the fundamental RF tone at 4.83GHz is obtained.**

I. Introduction

Mode-locked lasers are an attractive source of short ($\sim$picosecond) optical pulses at GHz repetition rates. In particular passively mode-locked devices are of great interest since no radio-frequency (RF) signal is needed to drive the laser. Because of the excellent characteristics of the generated pulse train, the mode-locked laser is gaining interest as a compact microwave signal source essential in microwave photonic applications. Integration of such mode-locked lasers on a silicon photonics platform allows using low-loss silicon waveguide structures to form the laser cavity, which positively affects the RF linewidth and optical output power. Moreover, high-speed optical detectors and modulators can be co-integrated on the silicon photonics platform, allowing the realization of complex photonic integrated circuits. Recently, III-V-on-silicon mode-locked lasers were reported based on classical self-colliding linear cavity designs and colliding ring cavity designs. A 15 kHz 3 dB RF linewidth (at 9.95 GHz repetition rate) and a 16 kHz 3 dB RF linewidth (at 4.7 GHz repetition rate) were obtained in a linear cavity design with on-chip feedback [1] and in a ring cavity device [2] respectively.

The purity of the mode-locked laser RF spectrum and its output power are critical in microwave applications. In this paper we demonstrate a novel anti-colliding cavity design implemented on the III-V-on-silicon waveguide platform where the saturable absorber is implemented on the low-reflectivity outcoupling mirror of the laser cavity. The theoretical analysis of such a cavity predicts an increase in output power and a reduction in amplitude and timing jitter compared with standard self-colliding pulse designs [3]. The demonstrated laser shows a 1.7 kHz 3 dB RF linewidth at 4.83 GHz, a substantial improvement over the state-of-the-art.

II. Device structure and design

The device geometry is shown in figure 1. The optical amplifier and the saturable absorber are implemented in the III-V-on-silicon waveguide section. The III-V gain section is 650 μm long (not including the 150 μm long spotsize converters), while the III-V saturable absorber is 65 μm long. The confinement factor of the optical mode in the quantum wells is 7.5 % both in the gain section and in the saturable absorber. A 150 μm-long tapered spotsize converter is used to couple between the hybrid gain section and the passive waveguide section as described in [2]. More details on the device fabrication and dimensions can be found in [2].

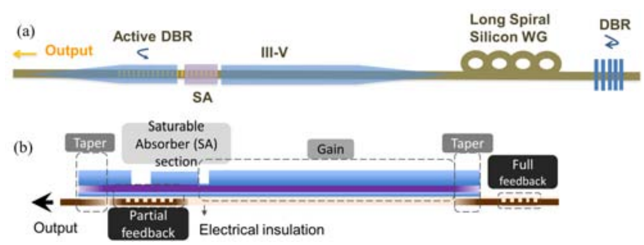

Fig. 1. Schematic diagram of the integrated mode-locked laser: (a) top view, (b) longitudinal cross-section.

The main part of the cavity length is formed by a silicon spiral waveguide of 0.7 cm length in order to reach a pulse repetition rate of about 5 GHz (4.83 GHz in the experiment). The laser cavity mirrors are also fabricated in the silicon waveguide layer. A high reflectivity cavity mirror is created by a broadband silicon distributed Bragg reflector (DBR) mirror (period 505 nm, 75 % duty cycle, 40 μm long) providing close to 100 % reflectivity at the right end of the laser cavity. The second cavity mirror is formed by a silicon DBR grating implemented partly underneath the saturable absorber, as is shown in figure 3. This grating has a 490 nm period, 75 % duty cycle, a total length of 100 μm and extends 40 μm under the output III-V spotsize converter. According to simulations the peak reflectivity and bandwidth of this grating depend on the thickness of the DVS-BCB bonding layer, as can be seen in figure 2. Qualitatively, a thinner bonding layer results in a wider bandwidth reflectance spectrum, with a red-shift of the spectrum peak. For a 75 nm thick DVS-BCB bonding layer as used in the experiment, see figure 3, this yields a peak reflectivity of 60% and a 3 dB bandwidth of 4 nm.

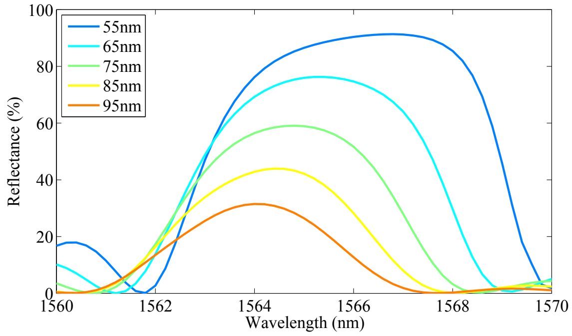

Fig. 2. The impact of bonding layer thickness on the reflectance spectra of the gratings simulated with a full vectorial Maxwell solver tool (CAMFR).

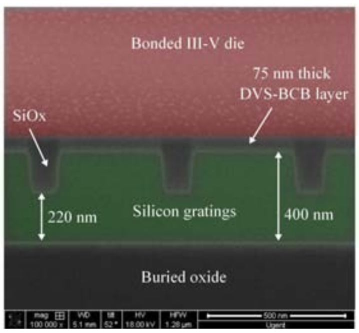

Fig. 3. SEM picture of the bonding interface at the saturable absorber.

III. Measurement results

The light-current characteristic of the realized device is shown in figure 4, as a function of saturable absorber reverse bias. At thermal roll-over the waveguide coupled output power is over 9 mW for a -0.7 V reverse bias voltage on the saturable absorber, substantially higher than previously reported III-V-on-silicon mode-locked laser geometries (ring cavity and linear cavity colliding pulse lasers) with similar dimensions implemented using the same technology [2]. The dips observed in the light-current characteristics are attributed to parasitic reflections from the grating coupler used for fiber coupling.

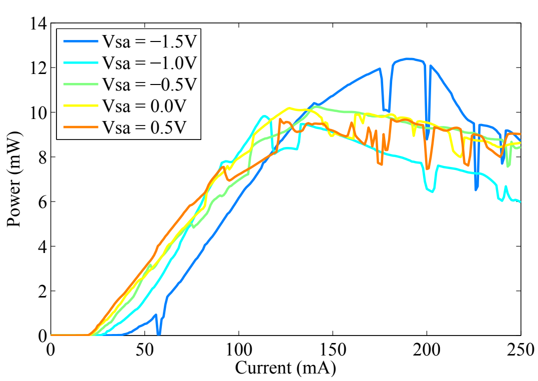

Fig. 4. Power versus current plot of the anti-colliding mode-locked laser as a function of saturable absorber reverse bias voltage.

For the passive mode-locking experiments, a reverse bias voltage of -0.7 V was applied to the saturable absorber and 61 mA current is injected in the spotsize converters and semiconductor optical amplifier as these settings resulted in the most flat RF spectrum of the generated pulse train. The measurements were carried out with the device on a thermo-electric cooler set at 20 °C. Figure 5 shows a high-resolution optical spectrum generated by the mode-locked laser. A 3.5 nm 10 dB optical bandwidth is obtained.

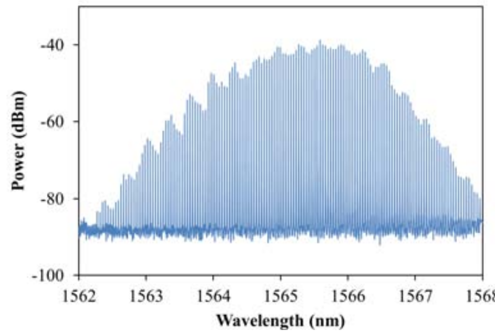

Fig. 5. High resolution optical spectrum at 61 mA drive current and -0.7 V reverse bias on the saturable absorber showing the 40pm spaced longitudinal modes (20MHz spectral resolution). A 10 dB optical bandwidth of 3.5 nm is obtained.

Next, the output of the laser was detected using a 50 GHz photodiode and observed on an electrical spectrum analyzer (ESA). The linewidth of the fundamental RF tone (at 4.83 GHz) is very narrow: a 1.7 kHz 3 dB linewidth (5 kHz 10 dB linewidth) is observed, as shown in figure 6, a substantial improvement over the state-of-the-art.

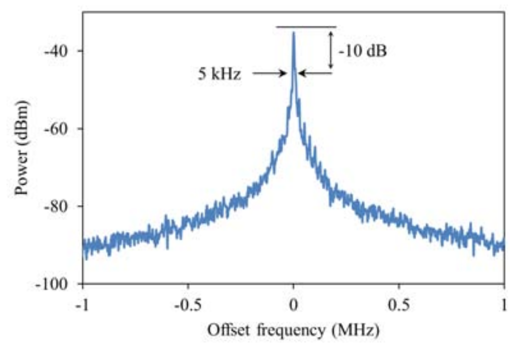

Fig. 6. Linewidth of the fundamental RF tone (resolution bandwidth and video bandwidth used to obtain the RF spectrum were 1.5 kHz and 150 Hz).

References

[1] S. Srinivasan, M. Davenport, M. J. Heck, J. Hutchinson, E. Norberg, G. Fish, and J. Bowers, "Low phase noise hybrid silicon mode-locked lasers," *Frontiers of Optoelectronics*, vol. 7, no. 3, pp. 265–276, 2014.

[2] S. Keyvaninia, S. Uvin, M. Tassaert, X. Fu, S. Latkowski, J. Mariën, L. Thomassen, F. Lelarge, G. Duan, P. Verheyen *et al.*, "Narrow-linewidth short-pulse iii-v-on-silicon mode-locked lasers based on a linear and ring cavity geometry," *Optics Express*, vol. 23, no. 3, pp. 3221–3229, 2015.

[3] J. Javaloyes and S. Balle, "Anticolliding design for monolithic passively mode-locked semiconductor lasers," *Optics letters*, vol. 36, no. 22, pp. 4407–4409, 2011.