Passively mode-locked III-V-on-silicon laser with 1 GHz repetition rate

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Abstract: *We present an on-chip III-V-on-silicon mode-locked laser at 1.6 µm with a 1 GHz repetition rate and -6 dBm output in the waveguide. The optical spectrum showed a 10.8 nm wide comb, the corresponding pulses showed an autocorrelation trace FWHM of 11 ps. A high purity RF spectrum was measured.*

Keywords: *mode-locked lasers, silicon photonics, semiconductor lasers, photonic integrated circuits*

1. INTRODUCTION

Integrated semiconductor mode-locked lasers (MLLs) have a wide range of applications and have gained a lot of interest as an integrated optical frequency comb source. While MLLs with repetition rates of tens of GHz are explored for e.g. optical communication applications [1], MLLs with low repetition rate (~ 1 GHz) are appealing for applications such as dual comb spectroscopy [2]. As these low repetition rate MLLs need long cavities, due to the associated high round trip propagation loss integration has proven to be very difficult. In this paper, by leveraging the low optical loss of silicon photonic wire waveguides, we present an on-chip III-V-on-silicon MLL with a 1 GHz repetition rate. This is, to the best of our knowledge, the lowest repetition rate that has been achieved by integrated passive MLLs to date. The measured 10 dB bandwidth of the optical comb is 10.8 nm, resulting in more than a 1000 longitudinal modes.

2. DESIGN AND FABRICATION

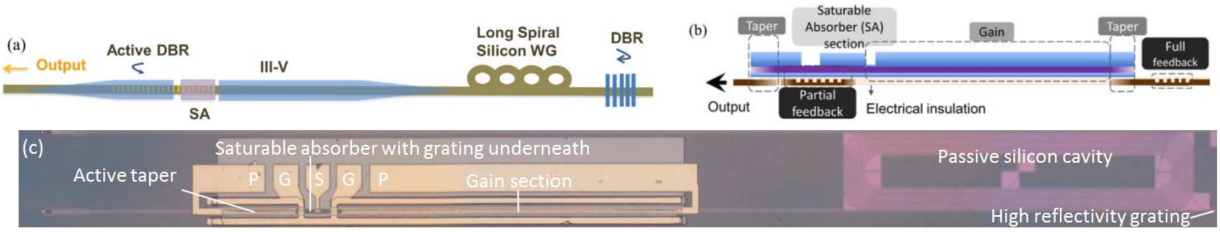

Figure 1 (a) Top and (b) side views of the MLL design. (c) Microscope image of the III-V-on-Si MLL.

The III-V-on-silicon MLL was realized by heterogeneously integrating a III-V gain section and saturable absorber (SA) on top of a passive silicon-on-insulator circuit which consists of low-loss waveguides (~0.7 dB/cm) and distributed Bragg reflectors defined in a 400 nm thick silicon layer on top of a 2 micron buried oxide. A more detailed description of the integration process based on adhesive die-to-wafer bonding can be found in [3]. The active material is an InGaAsP based MQW epitaxial stack. The 800 µm long gain section is split into two parts by a 40 µm long SA, implemented as a reverse biased gain section (see Fig. 1a). The SA is formed by etching 15 µm wide electrical isolating slots in the p contact layer. Instead of being placed next to the high reflectivity mirror, the SA sits on the low-reflectivity out-coupling mirror of the laser cavity, resulting in a so-called anti-colliding MLL configuration. The theoretical analysis of such a cavity under passive mode-locking points to higher output power, lower timing jitter and a better RF spectral purity compared to standard self-colliding pulse designs [4]. 200 µm long tapers are employed at both sides of the active section for adiabatic optical coupling between the III-V section and the passive silicon waveguides. Within the taper, the silicon waveguide width is tapered from 0.2 µm to 2 µm while the III-V waveguide is tapered from 3 µm to 0.8 µm. The passive silicon waveguide length is 37.4 mm in order to reach a 1 GHz repetition rate, and is terminated by a high reflectivity distributed Bragg grating. In addition, a grating coupler is fabricated at the output waveguide for vertical light extraction to a standard single mode fiber.

3. PASSIVE MODE LOCKING RESULTS

A Peltier temperature-controlled stage was used to keep the sample at 20 ºC during the measurement. The MLL was contacted using a 100 µm pitch PGSGP probe. The P contacts were used to bias the active taper outside the laser cavity and the gain section, the S contact was used to reverse bias the SA. The two G contacts formed a common ground for the gain section, active taper and SA. Light was collected using a standard single mode fiber, an isolator was inserted to prevent back-reflections into the laser cavity. The silicon waveguide coupled output was -6 dBm. After being amplified by an L-band EDFA the optical signal was split and simultaneously monitored by a high resolution Optical Spectrum Analyzer (OSA), an autocorrelator and a 50 GHz photodiode connected to a 43 GHz Electrical Spectrum Analyzer.

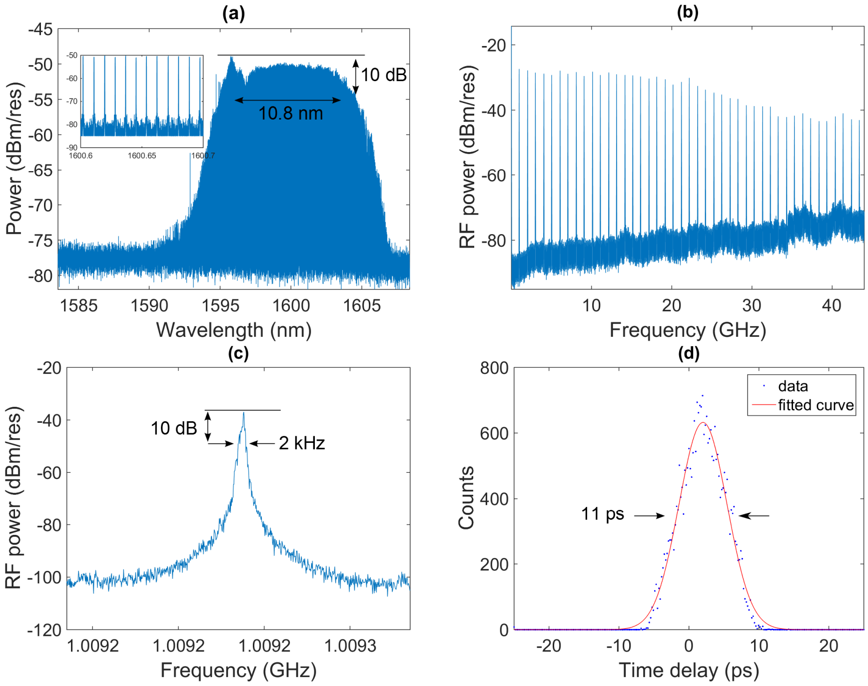

Figure 2 (a) Optical spectrum taken with a high resolution optical spectrum analyzer. The inset shows a detail of evenly spaced optical modes within the comb. (b) RF spectrum of the generated pulse train (RBW 300 KHz, VBW 10 KHz) (c) Detail of the 1 GHz RF tone (RBW 0.51 kHz, VBW 0.51 kHz) (d) Auto correlation trace of the MLL output, the Gaussian fit shows a FWHM of 11 ps.

The measured optical spectrum, under the optimal operation condition (91 mA current injection in the gain section, and -2.61 V bias on the SA), is shown in Fig. 2 (a). The optical comb has a 10 dB bandwidth of 10.8 nm. The inset of Fig.1(a) shows a detail of the spectrum around 1600 nm, where the optical modes can be clearly distinguished, with a spacing of 1 GHz. The electrical spectrum generated by the beat notes of the optical modes on the photodiode is shown in Fig.2(b). A strong fundamental tone 55dB above any spurious peaks / noise floor can be observed, indicating that there is very little residual amplitude modulation of the pulse train. The 3dB bandwidth of the RF comb is 19 GHz, while the 10dB bandwidth is 42 GHz. In Fig.2(c) a detail of the fundamental tone is shown. It was recorded with a resolution bandwidth and video bandwidth of 0.51 kHz, and the shown trace was averaged over 30 sweeps with an acquisition time of 1.10 s per sweep. The exact repetition rate of the MLL is found to be 1009.234 MHz, very close to the designed repetition rate. The measured 10 dB bandwidth of the fundamental RF tone is 2 kHz, which is very small for a passively mode-locked device and is related to the long passive section in the laser cavity. Fig.2(d) presents the optical autocorrelation trace of the pulse. A full width at half maximum (FWHM) of 11 ps is extracted by a Gaussian fitting procedure. This confirms that the MLL outputs a stable pulse train, which was independently confirmed by measurements with a 160 Gigasamples per second real-time oscilloscope (results not shown here). These results show superior performance to other low rep-rate integrated mode-locked lasers in terms of comb width, RF spectrum and time domain characteristics [5][6][7].

4. CONCLUSION

An integrated MLL with a record-low 1 GHz repetition rate and a 10.8 nm wide optical comb was realized on the III-V-on-Silicon platform. Applications of such a source are envisioned in the context of on-chip dual comb spectroscopy.

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