Numerical Analysis of Digital Pulse Modulation of Strongly Injection-Locked Whistle-Geometry Microring Lasers

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The potential of strongly injection-locked whistle-geometry semiconductor ring lasers for digital pulse modulation is investigated. Pulse modulation with up to 50 GHz repetition rate and substantially suppressed transient behaviour is demonstrated in numerical modelling.
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INTRODUCTION

Directly modulated laser sources with very high modulation bandwidths exceeding 100 GHz are highly desirable for the rapidly growing applications of RF optical fibre links. Optical injection locking has been actively researched for its potential to improve ultrahigh frequency performance of semiconductor lasers and to reach beyond the record values of modulation bandwidth achieved for free-running devices [1]. We have proposed an optical injection-locking scheme for modulation bandwidth enhancement, involving a distributed-Bragg-reflector (DBR) master laser monolithically integrated with a strongly injection-locked unidirectional whistle-geometry microring laser (WRL), illustrated in Fig. 1 [2]. Enhanced ultra-high-speed performance of that scheme in response to small-signal sinusoidal modulation has been confirmed in numerical modelling [2]. Large-signal analogue modulation has also been investigated and advantages of strong injection locking for high-fidelity large-signal modulation have been confirmed through numerical modelling by comparing high-speed performance of a strongly injection-locked WRL with that of a free-running ring laser [3]. In this work, we investigate the potential of strongly injection-locked WRLs for digital pulse modulation. Specifically, we address the question of potential optical output signal distortion due to transient behaviour of the laser in response to picosecond input pulses of injection current.

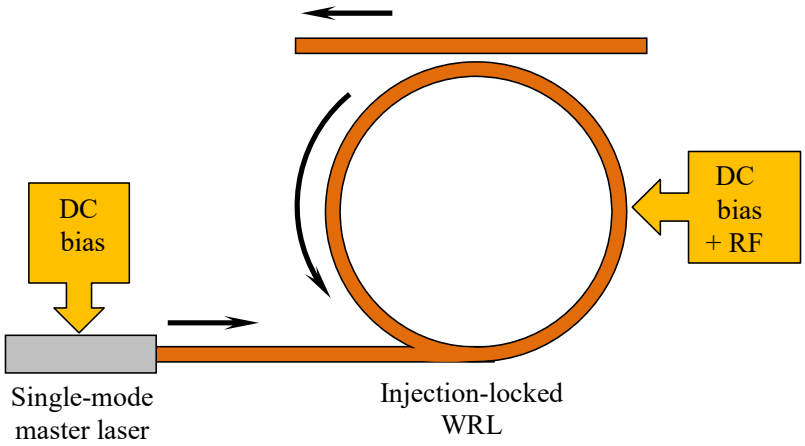

Fig. 1. Schematic diagram of a strongly optically injection-locked whistle-geometry semiconductor ring laser (WRL) monolithically integrated with a single-mode master laser.

APPROACH

Optical response of strongly injection-locked WRL to triangular injection current pulses of picosecond duration was investigated. The dynamic response of the WRL was modeled by a system of first-order rate equations written in terms of the photon densities, phases, and carrier densities in the single-frequency master and microring slave lasers. Parameters used for simulation were calculated for both the 50-µm long master DBR and the 2-µm-diameter ring lasers based on a deeply etched ridge-waveguide laser structure optimized for single-mode operation,

assuming a 1.55-µm GaInAs/AlGaInAs/InP multiple-quantum-well epitaxial structure of [4] with 7, rather than 6, quantum wells. The power reflectivity of the back DBR mirror was assumed to be 100%, whereas that of the front injecting DBR mirror was calculated at 1.55 µm wavelength to be ~82.5% for the front mirror consisting of two quarter-wave layers of benzocyclobutene (BCB) and one quarter-wave layer of semiconductor (refractive index equal to neff) in between, separating the identical ridge waveguide structures of the master laser and the injecting waveguide. We neglected the bending radiation losses under the assumption that the 2-µm-diameter WRL will eventually be implemented in a photonic-crystal-waveguide-based platform.

RESULTS

Special conditions have been determined in terms of the frequency detuning and injection current pulse duration for controlling the optical response in order to suppress transients. Pulse modulation of a 2-µm-diameter strongly injection-locked WRL with up to 50 GHz repetition rate with substantially suppressed transient emission tails and sufficiently high signal-to-noise ratio (S/N) has been demonstrated in numerical modeling for a sequence of triangular injection current pulses of picosecond duration (Fig. 2).

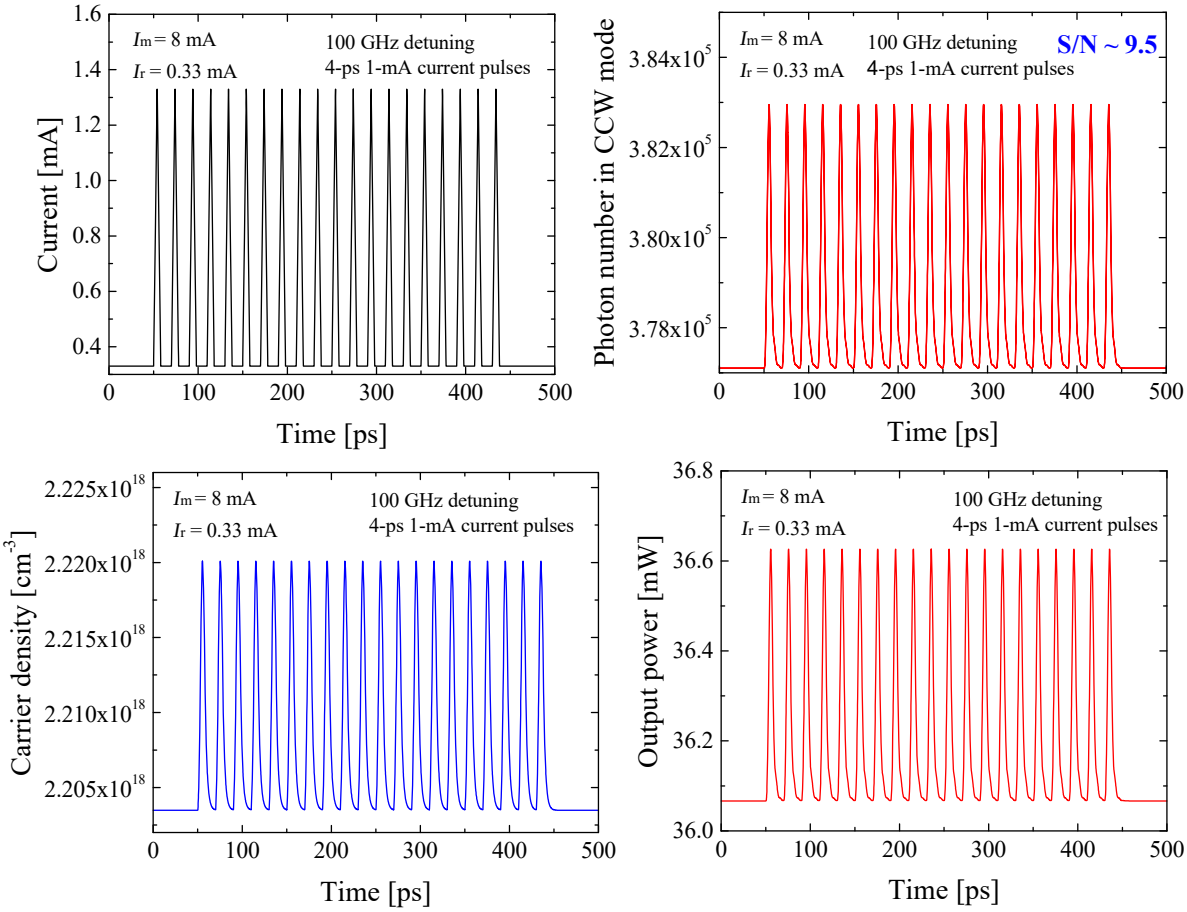

Fig. 2. Calculated optical and carrier density response of a strongly injection-locked WRL to a sequence of "one" bits, each bit represented by a triangular 4-ps injection current pulse of 1-mA amplitude, with the repetition rate of 50 GHz.

CONCLUSION

In conclusion, rate equation analysis has been performed of digital pulse modulation in a strongly injection-locked 2-µm-diameter whistle-geometry semiconductor ring laser. Digital data transmission rate of, at least up to 50 Gb/s has been predicted. Further improvement of S/N ratio and, therefore, higher repetition rates are possible for WRLs with higher differential gain (*e.g.*, in strained QW laser structures).

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