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Asymmetric Heterogeneously Integrated InP Microdisk Lasers on Si for Optical Interconnect and Optical Logic

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Abstract: We discuss properties and applications of heterogeneously integrated microdisk lasers coupled to an asymmetrically reflecting bus waveguide. Specific properties of interest for optical interconnect are unidirectionality and sensitivity to external feedback. We also discuss the application of such lasers for low power all-optical signal regeneration.
OCIS codes: (140.3460) Lasers; (130.3120) Integrated optics devices; (230.1150) All-optical devices.

1. Introduction

InP microdisk lasers, heterogeneously integrated onto silicon-on-insulator passive circuits, have been studied since several years. Optimisation of the bonding technology, of the lithographic processes and of the laser design now allow to fabricate such microdisk lasers with high yield, uniform characteristics and good performance [1]. Due to their small size and the use of an InP membrane, such microdisk lasers exhibit single mode operation with very small threshold currents of below 0.5mA and, as they don't require any facet reflections for their operation, they can be easily integrated with other components. Arrays of microdisk lasers with different diameter and all coupled to the same silicon bus waveguide can easily be implemented and can be used as multiwavelength light sources for all-optical interconnect [2,3]. For such optical interconnect applications, the microdisk lasers operate preferentially in a predefined unidirectional mode to give maximum efficiency. They should also operate relatively undisturbed by external reflections (coming from e.g. other components in the interconnect). In this paper, we therefore analyze the unidirectional operation and the external feedback sensitivity [4].

Furthermore, it has been demonstrated that these lasers can be used in diverse signal processing applications such as all-optical gating, all-optical flip-flops, wavelength conversion, etc. [2,5]. However, one of the conditions for optical logic to become competitive with electronic logic is the possibility for signal refreshing or regeneration [6]. We will describe below how microdisk lasers with different reflection for the clockwise and the counter clockwise direction are very well suited for such signal regeneration and we experimentally demonstrate BER improvement at 10 Gb/s. The optical signal regeneration is also obtained for sub-mW input power levels [7].

It is remarked that most signal processing applications, including regeneration, are based on injection locking of the microdisk lasers. As different microdisk lasers on the same die can be fabricated with very uniform emission wavelength characteristics [1], and since some degree of thermal tuning can easily be implemented [2], this does however not pose any problems for more complex photonic integrated circuits of which the operation relies on multiple microdisk lasers.

2. Unidirectional operation and feedback sensitivity of microdisk lasers with asymmetric coupling

There have been a few reports on unidirectional lasing of ring or disk lasers in a predefined direction, and mostly the unidirectionality is demonstrated qualitatively [8]. We have fabricated microdisk lasers, coupled to a bus waveguide which had a strong Bragg reflector on one side and a parasitic reflection on the other side. Dummy bus waveguides with equal Bragg reflector were also fabricated to characterize reflection and transmission from the Bragg reflector. The output powers coupled through grating couplers on both sides were measured vs. bias current and vs. wavelength. Taking into account the transmission of the Bragg grating, we can derive that the ratio of clockwise and counter clockwise powers inside the microdisk is 8dB. Even though the Bragg reflector reflects close to 100%, the 1-2% coupling between bus waveguide and microdisk makes that the microdisk laser sees an extra reflection of only a 1-2%.

A more complete understanding has been obtained from analytical approximations of the coupled wave equations [4]. It has been shown that at low to moderate power levels in the disk, the ratio of the powers in the clockwise and counter clockwise modes is given by the ratio of the respective reflections that these modes are subject to (or more accurately, the ratio of the coupling coefficients, also including the scattering in the microdisk itself). At higher power levels however, the ratio of powers in CW and CCW modes is determined by the gain suppression and a high degree of unidirectionality can exist even for a minor degree of asymmetry in the coupling or reflection. The laser will thus emit in the direction that has the least total reflection. From the coupled wave equations, one can simultaneously also derive the sensitivity to external feedback. It can be concluded that microdisk lasers are under most circumstances more reflection sensitive than edge-emitting lasers and such external reflections must be avoided as much as possible in photonic integrated circuits, or integrated isolators must be included. Only at very high power levels is a much lower reflection sensitivity obtained.

3. Application in low power optical signal regeneration

An injected exernal optical signal, when within the injection locking bandwidth of the microdisk laser, is equivalent to an external reflection with an amplitude P_{inj}/P_{out}. Hence, if a laser is operating unidirectionally in e.g. the CW direction because the reflection from the right hand side is slightly larger than the reflection from the left hand side, the injection of an external signal from the left hand side can make the equivalent reflection from the left hand side larger than that from the right hand side and make the microdisk laser switch from operation in the CW direction to operation in the CCW direction. This switch in direction is very abrupt and allows to obtain a regeneration characteristic as in Figure 1 (lhs), which is obtained from numerical solutions of the coupled wave equations. The location of the decision point is determined by the asymmetry in reflection or coupling coefficients.

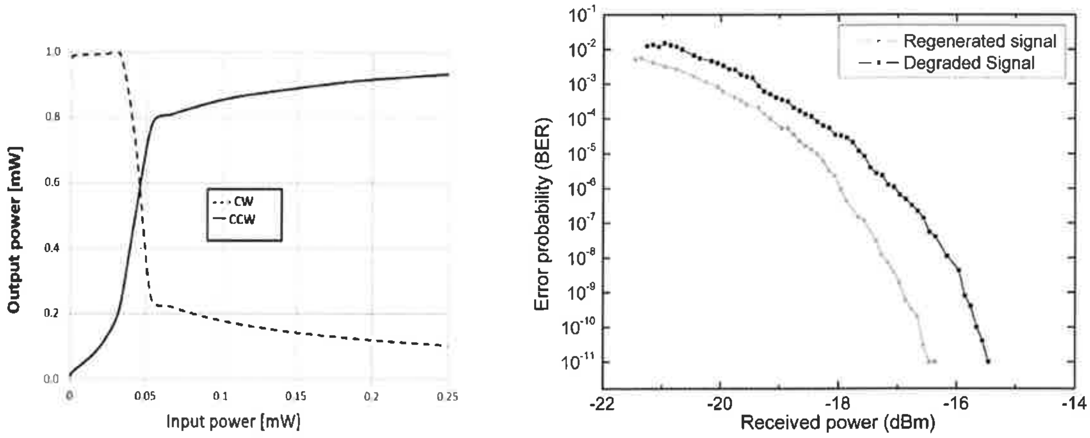

Figure 1. Static 2R regeneration characteristic for a asymmetric microdisk laser (lhs) and BER curves obtained experimentally at 10 Gb/s with a microdisk laser of diameter 7.5µm.

This type of signal regeneration was also demonstrated experimentally using a 10Gb/s input signal with power level below 1mW. BER vs. received power is shown in Figure 1 (rhs) for original and regenerated signal.

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